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G-33-611

Final Technical Report

NSF-Grant GP-8708

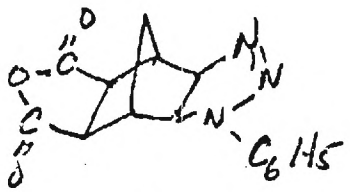
"The Chemistry of Bicyclic Triazolines and Related Compounds"

June 1968-December 1972

Leon H. Zalkow, Principal Investigator

SUMMARY

Previous reports[1,2,3] from this laboratory have shown that exo triazolines, such as 1, decompose under pyrolysis conditions to give predominantly endo aziridines, such as 2. The formation of a diazoimine intermediate 3 has been proposed to explain these observations. We now present the first successful synthesis of an endo triazoline.



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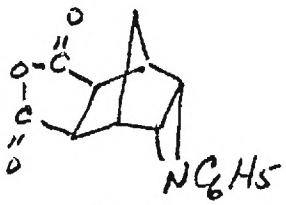

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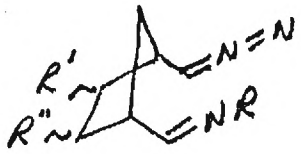

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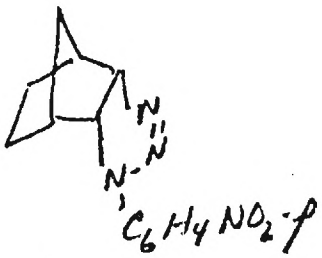
The synthesis of endo triazoline 4 involves the preparation of two key intermediates, endo amine 5 and diazoamine 6. The latter compound was cyclized to the endo triazoline with sodium ethoxide and an ethanolic silver nitrate solution. Photolysis of 4 gave endo aziridine 7. Pyrolysis of 4 produced endo aziridine 7, exo aziridine 8, imine 9 and additionally a significant amount of polymeric material. The formation of the exo aziridine 8 provides evidence for the formation of a common intermediate, such as 3, in triazoline pyrolyses.



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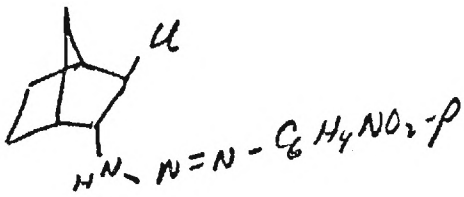

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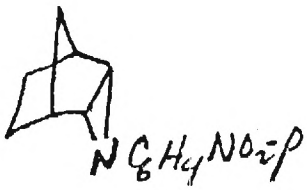

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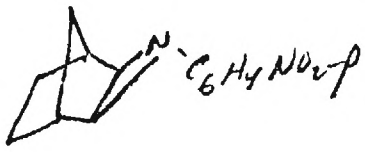

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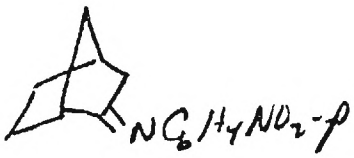

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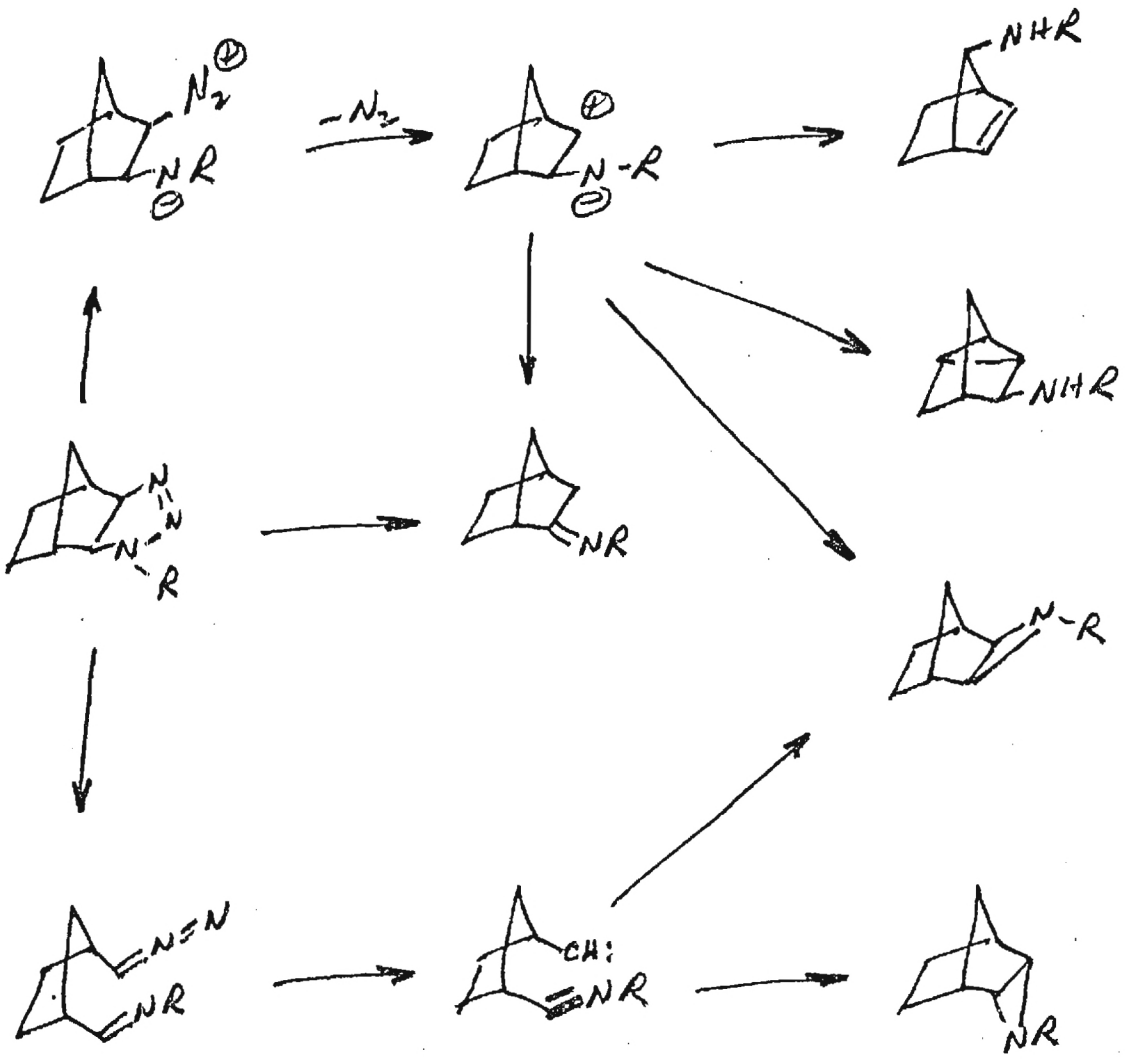
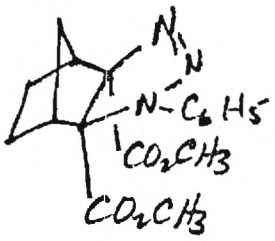
New mechanisms have been suggested to explain the diverse results of triazoline pyrolyses. A concerted formation of a diazoimine has been postulated, which subsequently loses nitrogen to form a triplet carbene which then may add to the imine to form aziridines. A concerted imine formation from a triazoline has also been proposed. A diazonium betaine has been proposed to explain the formation of certain ionic products observed in some pyrolyses. Additionally, the unexpectedly predominant formation of endo aziridines, such as 2, from the pyrolyses of certain triazolines containing anhydride or ester functions, such as 1, has been explained as the result of an exceedingly large field effect exerted by the anhydride function.



In a supplemental study, exo triazoline 10 was prepared and its chemistry studied. Photolysis of 10 gave exo aziridine 11. Unexpectedly, pyrolysis of 10 did not produce 11, but instead an unstable compound,



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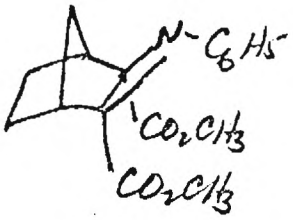

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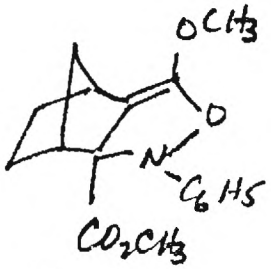

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poltulated to be isoxazoline 12. Although the structure of 12 was not conclusively established, infrared, NMR, and mass spectra provide excellent evidence for this structure.

DISCUSSION OF RESULTS*

One of the goals of this work was to devise a general synthetic route to the heretofore unknown bicyclic endo triazolines. An analysis of the synthetic problem shows that an endo (3+2) cycloaddition of a 1,3-dipole to norbornene is unknown[4,5]. Indeed this steric interference is so great that when the exo approach is blocked by substituents on the methylene bridge, as in the case of apobornylene, there is no azide addition at all.[4] This hindrance was further substantiated by results from this laboratory.

N-aminophthalimide was oxidized with lead tetraacetate to give, presumably the aminonitrene,[6] which unfortunately did not add to bornylene to give the endo aziridine. It was anticipated that if the desired endo aziridine had been obtained it could have been readily converted into the endo triazoline. Another approach to the problem was suggested by the

*Only results which have not appeared in a full paper are discussed with any detail.

work of McLean and Findlay[7] who isolated two endo triazolines in the reaction of norbornadiene with phenyl azide. The diene 13 was readily prepared by the (4+2) cycloaddition of cyclo pentadiene and dimethyl acetylene dicarboxylate. It was anticipated that the phenyl azide would react with the unhindered, electron rich double bond of the diene to yield the endo triazoline, which could then be selectively hydrogenated. This

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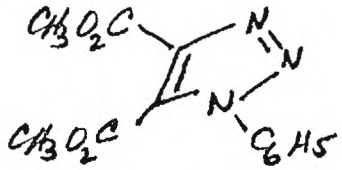

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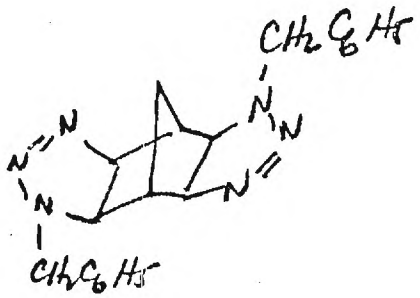
triazoline would be valuable in comparative pyrolysis studies since the exo isomeric triazoline has been previously prepared in our laboratory. The only product which could be isolated from this reaction, has been identified as dimethyl-1-phenyl-1,2,3-triazole-4,5-dicarboxylate, 14, on the basis of IR, UV, NMR and mass spectral analysis. Again, utilizing the approach of endo addition to a diene, benzyl azide was added to a refluxing cyclohexane solution of norbornadiene. Various ratios of benzyl azide to norbornadiene were used. In each case, the same two products were isolated via fractional crystallization. By spectral analysis these two products have been identified as the anti-di-exo triazoline 15 (m.p. 154-156°) and the syn-di-exo triazoline 16 (m.p. 168-170°). The results of the above experiment were not so surprising, since McLean and Findlay[7] reported only a low yield of endo triazolines. The bulk of the azide substituent was increased when the



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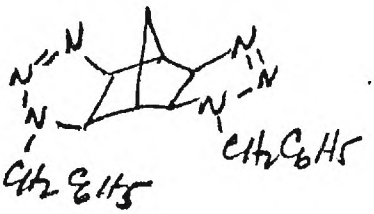

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benzyl azide was used in the place of phenyl azide, thus further decreasing the possibility of the endo addition.

The unfruitful results of the earlier proposed syntheses lead to an entirely new approach. It was reasoned that if the azide function would not add to the endo face of the bicyclic molecule, then this function might be incorporated within the molecule by other means. The pathway vizualized involved Diels-Alder reaction of cyclopentadiene with some moiety which could be converted to the desired product. Freshly prepared cyclopentadiene was refluxed with 1-benzyl 1,2,3-triazole for eight hours in an attempt to prepare the endo-triazoline. When the mixture was cooled with dry ice, only the starting triazole was recovered. In a related reaction 2-imidazolone and cyclopentadiene were stirred in 95% ethanol but again only unreacted starting materials were recovered. Higher temperatures did not facilitate the reaction.

With the failures of the preceding pathways, it was obvious that an entirely novel pathway to an endo triazoline must be devised. The envisioned route would involve an intermediate which would contain an endo amino moiety as well as exo substituent on the alpha-carbon, which might be displaced by this endo group. This amino compound could be prepared from an imine or oxime.

The nitrosyl chloride dimer of norbornylene was prepared as previously described[8] and isomerized to 3-chloronorcamphor oxime using urea as a catalyst.[9] The next step met with some difficulties. Attempted hydrogenation of this oxime in methanol with 5% rhodium on alumina at 56 psi gave an unidentified oil shown not to be the desired amine hydrochloride as demonstrated by the absence of the amino hydrogens in its infrared spectra. It was decided to acetylate the oxime, since there were reports that while oxime esters reduce to amines under mild conditions, oximes required more vigorous conditions. The oxime was stirred with an excess of acetic anhydride and pyridine (1:1) at room temperature overnight. The oxime acetate was isolated as an oil which showed characteristic bands in its infrared spectrum at 1770 cm^{-1} (ester) and 1660 cm^{-1} (oxime double bond). The NMR spectrum showed a hydrogen geminal to a chlorine as a doublet with J = 2.5 Hz at δ 4.34, one bridgehead proton in two different environments (<u>syn</u> and <u>anti</u> forms) as two multiplets centered at δ 3.48 (0.6 proton) and δ 3.03 (0.4 proton), one bridgehead proton as a multiplet centered at δ 3.57, three protons of an acetyl group in two different environments as two singlets at δ 2.10 and δ 2.07, and a complex region between δ 2.05 and δ 1.10 which integrated for six protons. The mass spectrum showed no molecular ion, but did show a m/e of 142 (48%), an ion formed from the loss of an acetoxy group from the unobserved molecular ion. The oxime acetate was dissolved in methanol and hydrogenated at 56 psi using 5% rhodium on carbon catalyst. Once again, upon work up of the mixture, the unidentified solid, previously isolated from hydrogenation of the oxime, was the product.

To the oxime acetate in ethanol was added sodium borohydride in ethanol. After nearly two hours, the reaction was worked up to give an oil which was identified as a mixture of *syn* and *anti* norcamphor oxime by infrared, NMR, and mass spectra and also by mixed injection with an authentic sample on g.l.c. This product probably originated from the oxime acetate by cleavage of the acetyl group, followed by dehalogenation, and finally reduction of the intermediate nitroso compound.

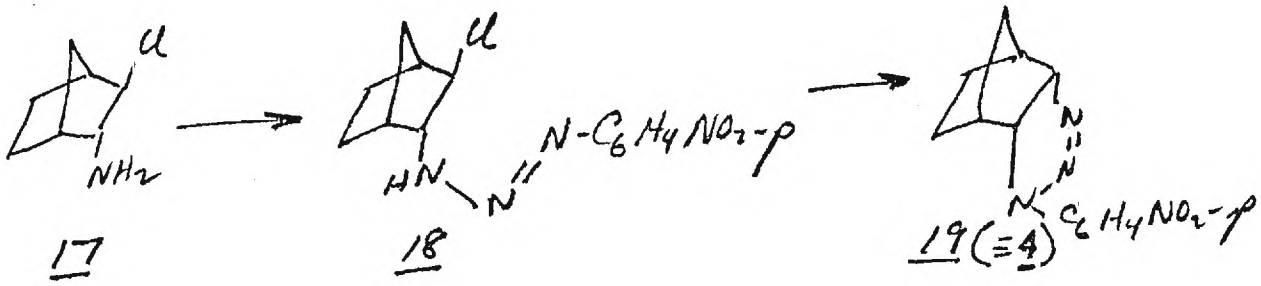
It was decided that other hydride reductions would lead to the same results and thus another reagent was sought. A literature survey revealed that oxime esters had been successfully reduced to primary amines by Feuer and Braunstein[10] with diborane. The oxime ester was subjected to hydroboration in tetrahydrofuran at room temperature overnight. The excess diborane was destroyed with water, the resulting white borate ester hydrolyzed with 10% hydrochloric acid for one hour, then the solution was made alkaline and extracted with ether. The combined ether extracts were dried, hydrogen chloride was bubbled into the ethereal solution and a white, flocculent precipitate appeared. This was identified as the *endo* amine hydrochloride (17%). The infrared spectrum of the salt showed bands at 1590, 1570, 1495 cm^{-1}, which are characteristic of amine salts. The NMR spectrum of this salt in trifluoroacetic acid and chloroform revealed a broad hump for three amine hydrogens centered at δ 7.08, which disappeared upon addition of deuterium oxide, two hydrogens as a multiplet centered at δ 3.63, one bridgehead proton as a multiplet centered at δ 2.50, one bridgehead proton as a multiplet centered at δ 2.32, and six hydrogens in a complex pattern in the region between δ 2.0 and δ 1.0.

The mass spectrum of the amine hydrochloride showed a m/e of 145 which corresponded to $C_7H_{12}ClN \cdot HCl$ minus HCl. Analysis of the white solid was consistent with the formula of the amine hydrochloride $C_7H_{12}N \cdot HCl$.

The free amine was obtained by treating the salt with an alkaline aqueous solution and then extraction with ether. The infrared spectrum of the free amine which had been treated with deuterium oxide had two bands at 2215 cm^{-1} and 2105 cm^{-1}. These bands were assigned to the N-D stretch of the deuterated amine. The NMR spectrum of the amine showed one hydrogen as a triplet centered at δ 3.36 with J of 3.5 Hz, one hydrogen as a triplet centered at δ 3.20 with J of 2.5 Hz, two bridgehead protons as a multiplet centered at δ 2.23, and eight protons in a complex pattern between δ 2.03 and δ 1.00. The amino protons were in the complex region between δ 2.03 and δ 1.00 and disappeared upon addition of deuterium oxide (the region then integrated for six protons). The two hydrogens at δ 3.36 and δ 3.20 were very close and appeared as two side by side triplets. However, the latter triplet is more likely a quartet and one of its peaks is underneath the triplet at δ 3.36. Observation of the general peak ratios leads to the same conclusion. NMR splitting patterns exhibited by the C-2 and C-3 protons of the free amine are complicated by the fact that they overlap. Using previously reported chemical shift data for the norbornane system[11] and a related rigid ring system containing vicinol chloro and amino groups[12] it is possible to predict the relative chemical shifts of the C-2 and C-3 protons in the chloroamine. On this basis the chemical shifts observed for the C-2 and C-3 protons in the chloroamine are more consistent with 2-<u>endo</u>-amino-3-<u>exo</u>-chloronorbornane than for the 2-<u>exo</u>-amino isomer. Conclusive proof of this stereo-chemical assignment, however,

was found in the ultimate conversion of this chloroamine to the desired endo triazoline by an intramolecular displacement of the exo chloro group as discussed in the sequel. By use of the oxime p-nitrobenzoate instead of the corresponding acetate, the yield of chloroamine was increased to 41%.

Heine and Tomilia[13] reported the coupling of aryl diazonium salts with unsubstituted aziridines to give diazoaziridines which could be converted into triazolines. We decided to use a modification of the procedure which involved coupling of the above mentioned chloroamine with an aryl diazonium salt to give a diazoamine which would be converted into the endo triazoline as outlined.



The diazonium salt of p-nitroaniline was prepared at 0° in the usual manner and the diazonium solution was poured into a saturated sodium acetate solution. The pH of this solution was adjusted to 5.6-6.0 by addition of solid sodium acetate trihydrate. This buffered solution was then added, a portion at a time, to the amine hydrochloride in water. A yellow precipitate immediately formed. After complete addition of the diazo solution, the mixture was stirred for one hour and the solid was collected by filtration. The yellow product was air dried (61%) and had a m.p. 112°-115° with bubbling. The infrared spectrum was consistent

with that expected for the coupled product 18 showing a secondary amine at 3380 cm^{-1} (in KBr) and at 3315 cm^{-1} (in $CHCl_3$). The ion of highest mass in the mass spectrum was the molecular ion minus molecular nitrogen at m/e of 266. It is interesting that the overall appearance of the mass spectrum of 18 is similar to that of the endo triazoline 4, perhaps indicating that the diazoamine closes to the triazoline prior to fragmentation. The NMR spectrum of 18 contained two aromatic hydrogens as a doublet with J of 9 Hz at δ 8.21, two aromatic protons as a doublet with J of 9 Hz at δ 7.26, a complex multiplet for one proton centered at δ 4.26, one proton as a triplet with J of 2.5 Hz at δ 3.89, two bridgehead protons as a complex multiplet centered at δ 2.54 and six hydrogens in a complex region between δ 2.22 and δ 1.10. Elemental analysis of this compound showed the structure was consistent with $C_{13}H_{15}ClN_4O_2$. By using the free amine 17 rather than beginning with its hydrochloride salt, the yield of 18 was increased to 81%.

The last step in the synthesis involved closure of the diazoamine to the desired endo triazoline by intramolecular nucleophilic displacement of chlorine. Preliminary experiments showed that the anion of 18, which was recognized by its deep red color, was easily formed by treatment with a strong base such as a tertiary amine or sodium hydride. However, it was further recognized that this anion was exceedingly stable, since the charge was largely delocalized. After refluxing this solution at 80° for eight hours, there was still no change in color. Thus it appeared that some additional driving force was required for the cyclization of this chlorodiazoamine.

The diazoamine 18 was dissolved in absolute ethanol and heated to 60°. To this was added slightly more than one equivalent of freshly prepared sodium ethoxide. The solution immediately turned a deep wine red, indicative of anion formation. This solution was stirred for thirty minutes and then one equivalent of solution of silver nitrate in ethanol was added. The color of the resultant solution, after complete addition, was yellow thus indicating a change had taken place. The solution was filtered several times and eventually upon complete work up, a yellow solid was isolated (64%; m.p. 120-130° with bubbling). Recrystallization from ethanol gave orange crystals, m.p. 135-138° with bubbling. The infrared spectrum contained the characteristic bands for a nitro grouping at 1500 cm^{-1} and 1320 cm^{-1}. The mass spectrum showed as the ion of highest mass a m/e of 230 which corresponds to the triazoline (4) minus molecular nitrogen. The NMR spectrum showed two aromatic protons as a doublet with J = 9 Hz at δ8.15, two aromatic protons as a doublet with J = 9 Hz at δ7.27, one allylic proton as a doublet of doublets with J's of 5.50 Hz and 12.0 Hz centered at δ5.09, one proton as a doublet of doublets with J's of 4.25 Hz and 12.0 Hz centered at δ4.02, two bridgehead protons as a complex multiplet centered at δ2.80 and six hydrogens in a complex region between δ1.65 and δ0.75 (see Appendix). The elemental analysis of the triazoline was consistent with that predicted for $C_{13}H_{14}N_4O_2$.

The clue to the identification of the endo triazoline is the NMR spectrum. The two protons which appear as doublets of doublets demonstrate that the triazoline function is indeed endo. The large coupling constant of 12 Hz is indicative of the cis exo C-2 and C-6 protons. These

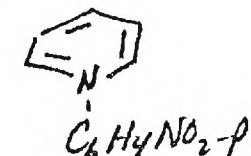
protons are also coupled with bridgehead hydrogens at C-1 and C-7 with J values of 4.25 and 5.50 respectively. Had the C-2 and C-6 protons been endo, the coupling constants with the bridgehead protons would have been near zero.[11] In contrast to the endo triazoline, the NMR spectrum of the isomeric exo triazoline shows the C-2 and C-6 protons as doublets, each with J values of 9 Hz.[14] (See Appendix.)

The study of the chemistry of this endo triazoline began with its photolysis. A mixture of the endo and exo triazolines (2:1, respectively) was photolyzed in acetone for six hours at -5°. There were two products (2:1) by g.l.c. analysis. The minor product was identified as the exo aziridine (8) by comparison on g.l.c. with an authentic sample and by comparison of the NMR of the mother liquor with that of the authentic sample. The major product was collected by preparative g.l.c. Reinjection of this sample showed that it was indeed pure and was the major product. This yellow solid was identified as the endo aziridine (7). The infrared spectrum contained bands at 1500 cm^{-1} and between 1350 cm^{-1} and 1300 cm^{-1}, in the region expected for an aromatic nitro group. The NMR spectrum contained two aromatic hydrogens as a doublet with J = 9 Hz at δ8.06, two aromatic hydrogens as a doublet with J = 9 Hz at δ6.91, two aziridine ring protons as a triplet with J = 2 Hz at δ2.93, two bridgehead protons as a multiplet centered at δ2.49, and a complex region for six hydrogens between δ2.03 and δ1.21. The mass spectrum showed a molecular ion at m/e of 230 for $C_{13}H_{14}N_2O_2$.

Mention should be made of the mixture of endo and exo triazolines used in the photolysis. This mixture was prepared from the amine hydrochloride which had been isolated from a large scale hydroboration of the p-nitrobenzoate oxime. The product from this reaction was impure. Two subsequent

purifications of this product gave the amine hydrochloride used to prepare the above mixture. It is interesting that in no other repetitions of the hydroboration were such mixtures isolated. These results demonstrated that the hydroboration of the p-nitrobenzoate oxime was not stereo-specific, although the extent to which the exo amine was formed was not known.

A rather distinct pattern appears to be observed in the mass spectral fragmentation patterns of aziridines in the norbornane series such as 7 and 8. Almost always the first significant ion (usually the base peak) observed after the molecular ion is that ion resulting from loss of an ethyl radical. This ion in many cases is so intense that it is often the base peak of the spectrum. Thus for exo and endo aziridines 7 and 8, the base peaks are at m/e 201 and this ion probably corresponds to a pyridinium structure 20. The significance of this observation is that it may be used



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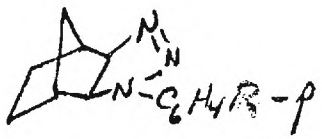
as a diagnostic tool to distinguish between these types of aziridines and their corresponding isomeric imines and enamines. Thus, in the mass spectrum of the imine (9), the loss of an ethyl group is only a minor pathway, ~ 12% (the base peak was the molecular ion). Probably the high intensity of the ion resulting from the loss of an ethyl group is a result of the large amount of ring strain within the tricyclic $\{3,2,1,0^{2,4}\}$ system. Further support for this observation is that the base peak for the aziridine (11) is also the result of loss of an ethyl radical.

Analysis of the NMR spectrum is again the key to the identification of endo aziridine (7). The triplet observed for the protons on the carbon attached to nitrogen is characteristic of endo aziridines.[1] This is in contrast to the NMR spectrum of the exo aziridine (8) in which the two endo hydrogens on the aziridine ring appeared as a singlet at δ2.42 and the anti C-8 proton appeared at δ0.87 as a doublet with J = 9.5 Hz. The high field position of the anti C-8 proton is characteristic of exo aziridines.

The concluding study of the chemistry of the endo triazoline was most significant. The endo triazoline (4) and the exo triazoline (21) were each pyrolyzed in decalin at 165-170° for two hours. The results of the g.l.c. analysis of each pyrolysate are summarized in the Table below.

TRIAZOLINE	ENDO AZIRIDINE (7)	IMINE (9)	EXO AXIRIDINE (8)	NON-VOLATILE PRODUCTS
Exo (90)	8.8	42.3	48.5	0%
Endo (89)	3.7	10.0	7.3	79%



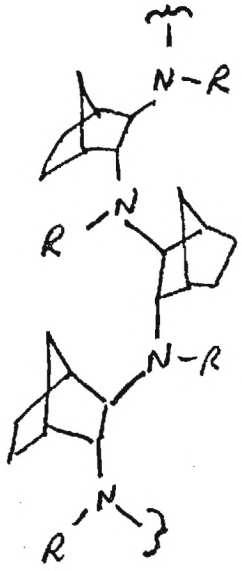
21 R = NO_2

22 R = H

It is important to point out that all products from the pyrolysis of exo triazoline 21 would be expected to be g.l.c. volatile as was demonstrated by previous[2,3,15,16] work. The results of this pyrolysis correlate well with earlier observations of similar pyrolysis of exo triazolines[2,3,15]

Thus, McDaniel and Oehlschlager[16] found that the pyrolysis of the closely realted triazoline 22 also produced an endo aziridine in 9% yield.

The results of the pyrolyses of endo and exo triazolines (4 and 21) provide evidence for a common intermediate, namely the diazoimine (see p. 3) which can produce both endo and exo aziridines. It should be pointed out that the ratio of endo to exo aziridines is only an apparent one, since the endo triazoline gave predominantly a non-volatile gum which may be polymeric material such as 23', derived by nucleophilic attack on the relatively unhindered exo face of the strained endo aziridine. It should be pointed out



23'

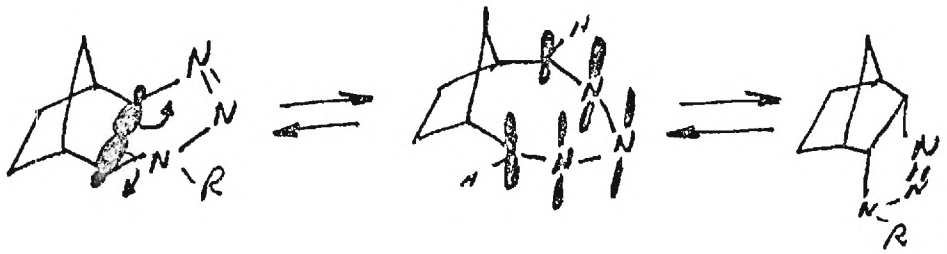
here that the endo triazoline was observed to lose nitrogen between 135-138°, about thirty degrees lower than for the exo triazoline. This may account for the high degree of polymerization observed since the decomposition was conducted at 165-170°! Also the fact that nitrogen liberation was observed for only the first fifteen minutes of the two-hour pyrolysis, probably

indicates that the triazoline had completely decomposed at that point and thus the additional heating time would have contributed to the formation of polymer. Perhaps also a factor in this side reaction is that the p-nitrophenyl substituent, being a strong electron withdrawing group, would facilitate the ring opening reaction by delocalization of any negative charge involved in the polymerization.

Further evidence[2] was obtained in this study to support the existence of an intermediate diazoimine (3) in the pyrolyses of triazolines. When triazoline 10 was pyrolyzed, a yellow oil was trapped which showed bands in the infrared region at 2120, 1720, 1695 and 1630 cm^{-1}, the latter band presumably being due to the imine double bond. The production of exo aziridine on pyrolysis of an endo triazoline, as observed in this study further suggests a common intermediate diazoimine in these pyrolyses. Two concerted mechanisms can be visualized that account for the formation of endo aziridines from exo triazolines or exo aziridines from endo triazolines. Both of these processes would be expected to involve disrotatory ring openings in accordance with the Woodward-Hoffmann Rules of orbital symmetry. Thus, a retro 1,3-cycloaddition, which is thermally allowed for a six-electron system, would yield the diazoimine as indicated below. The second possible pathway is an electrocyclic ring opening which is thermally allowed

Retro 1,3-Cycloaddition
of a Triazoline

for a six-electron system.



Electrocyclic Ring Opening
of a Triazoline

Both mechanisms seem equally plausible on a theoretical basis, however the reported observations of the formation of diazoalkanes and imines from triazolines[2] lead one to favor the retro 1,3-cycloaddition pathway. Furthermore, if the exo triazoline was indeed transformed into an endo triazoline, it should be observable by NMR temperature studies, since the endo triazoline would be expected to have a finite existence. This should particularly be true for triazoline which gives predominantly endo aziridine. This could not be observed. Also, had an endo triazoline been involved in the reactions in question, in cases where polar products, such as 24 and 25, are observed, it would be expected that comparable endo polar products would have been seen, i.e. 26, etc. Such products have not been reported.

24

25

26

27

Reconsideration of the observations by earlier workers[1,2,3,15,16] however leads one to the conclusion that in some cases this concerted pathway is in competition with the N-N cleavage which produces 27. That the rate of reaction increases with the polarity of the solvent suggests that indeed the ionic mechanism becomes prominent when there are solvent molecules which stabilize charge separation. Thus, while the ionic mechanism is favored in polar solvents, it would seem that the nonionic or concerted mechanism becomes the favored pathway in non-polar solvents. That there occurs a decrease in rearrangement products upon going from polar to a non-polar solvent, further indicates that the concerted process is the route of choice in non-polar solvents. Thus a higher endo:exo aziridine ratio would be expected from an exo triazoline in non-polar solvents. This is, in fact, what is observed. It is well known that diazoalkanes decompose under photolytic and pyrolytic conditions to form carbenes.[6] There is no reason to assume that the diazoalkane portion of the intermediate should deviate from normal behavior. Under normal pyrolysis conditions, the diazoalkane would be expected to decay to a triplet carbene, which would selectively add to the imine to produce the endo and exo aziridines. This would account for the results of the reactions of benzenesulfonyl azide with the norbornene derivatives. However, this triplet carbene cannot adequately explain the formation of imine in some instances or the formation of polar products in other instances. In the case of 22, the polar products obviously arise via some type of ionic mechanism, probably the diazonium betaine or a dipolar intermediate. However, in cases where imine is the only other product besides aziridines such as in this work, it becomes questionable as to whether an ionic mechanism is involved. This is particularly

true in light of the work of Saunders, Schleyer and Olah[17] who showed that Wagner-Meerwein rearrangements and 6,2-hydride shifts in the 2-norbornyl cation are much more rapid than 2,3-hydride shifts. To account for the imine formation, a concerted nitrogen loss and hydrogen shift may be postulated, as shown.

Concerted Formation of Imine

Summarizing, we observe that benzenesulfonyl azide adds to norbornene derivatives rapidly to yield aziridines and rarely imines.[2] Unstable exo triazolines have been assumed to be involved although they have never been detected. The inability to isolate these unstable triazolines is certainly linked to the nature of the decomposition process. Obviously the retro 1,3-cycloaddition to the diazoimine takes place almost immediately. The diazoalkane then decomposes to a carbene and adds selectively to form predominantly aziridines. As we move through the spectrum of triazoline substituents, we begin to see a general trend. An electron-withdrawing group such as p-nitrophenyl under pyrolysis conditions gives aziridines and imine, but no other products. We now see that the retro 1,3-cycloaddition reaction to give diazoimine is in competition with the concerted reaction which yields imine. If we consider the results of the N-phenyl substituted triazoline 22, we see that aziridines, imine and other more polar products are observed. At this point, we begin to see an ionic process in competition with the concerted processes. The various pathways are summarized in the diagram on p.3.

To account for the previously observed[2] high endo/exo ratio of aziridines in the reaction of benzenesulfonyl azide with cis-endo and cis-exo norbornene-5,6-dicarboxylic acid anhydrides and the cis-exo dimethyl ester, we now wish to suggest a very strong field effect exhibited by the anhydride or carbomethoxy groups. To explain this field effect one must accept, for the moment, the existence of this pathway which might lead to the observed endo and exo aziridine. Clearly if the imine portion of the intermediate alines itself with the dipole created by the anhydride in a head to tail fashion (i.e. negative to positive center), the conformation achieved will be 28. If the imine is in this configuration when the diazoalkane loses nitrogen to form a carbene, the product observed will be the endo aziridine. Indeed, further evidence for the field effect of the anhydride groups is present in the results of Zalkow and Oehlschlager[1] who reported that the relative rates of nitrogen evolution in the thermal reactions of benzenesulfonyl azide with norbornene, exo anhydride and endo anhydride are 100:10:1 respectively. The magnitudes of the field effects in question are demonstrated in earlier results. The reaction of benzenesulfonyl azide and norbornene, which produced a quantitative yield of the exo aziridines,[2] indicates that steric hindrance of the endo face of norbornene is so great that little or no endo aziridine may be formed without the influential field effect of the anhydrides or ester groupings. Secondly, it demonstrates that even with the greatly increased steric bulk with the substitution of the endo anhydride grouping for the endo hydrogens, the field effect is so strong that the endo aziridine prevails. Significant, however, is the fact that steric factors are too much to overcome in the case of the endo dimethyl ester, which upon reaction with benzenesulfonyl azide gave a 1:99 endo to exo aziridine ratio.

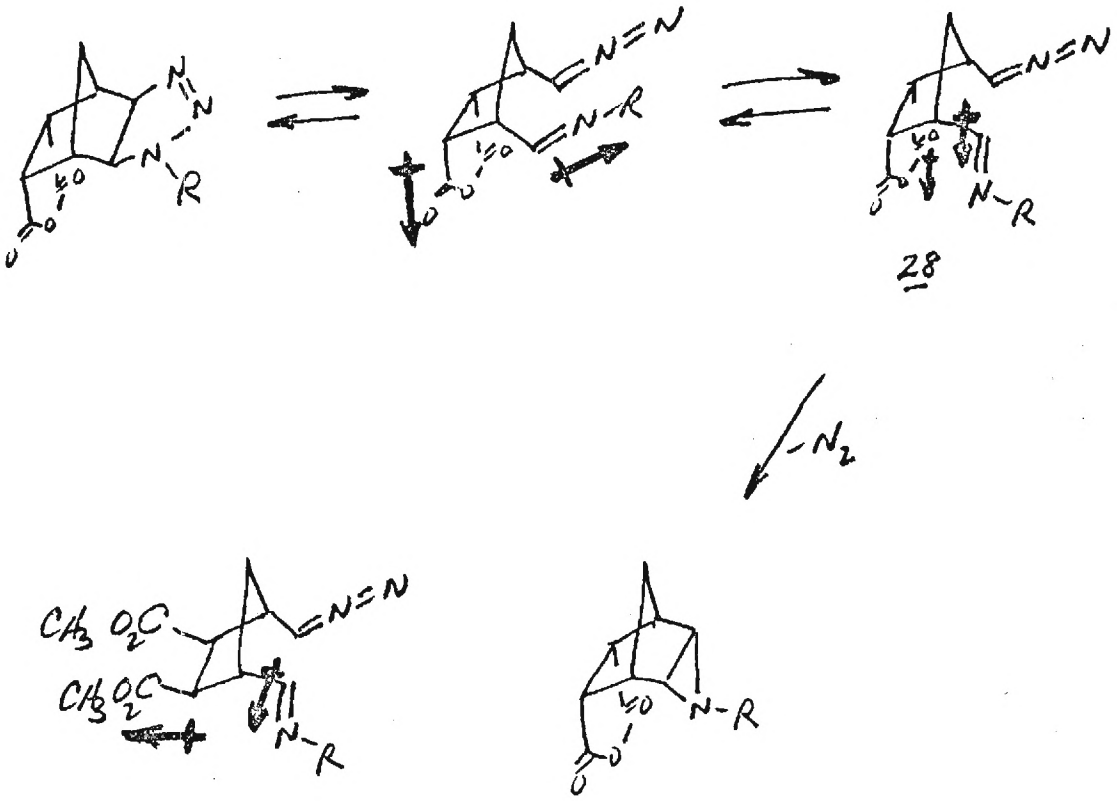
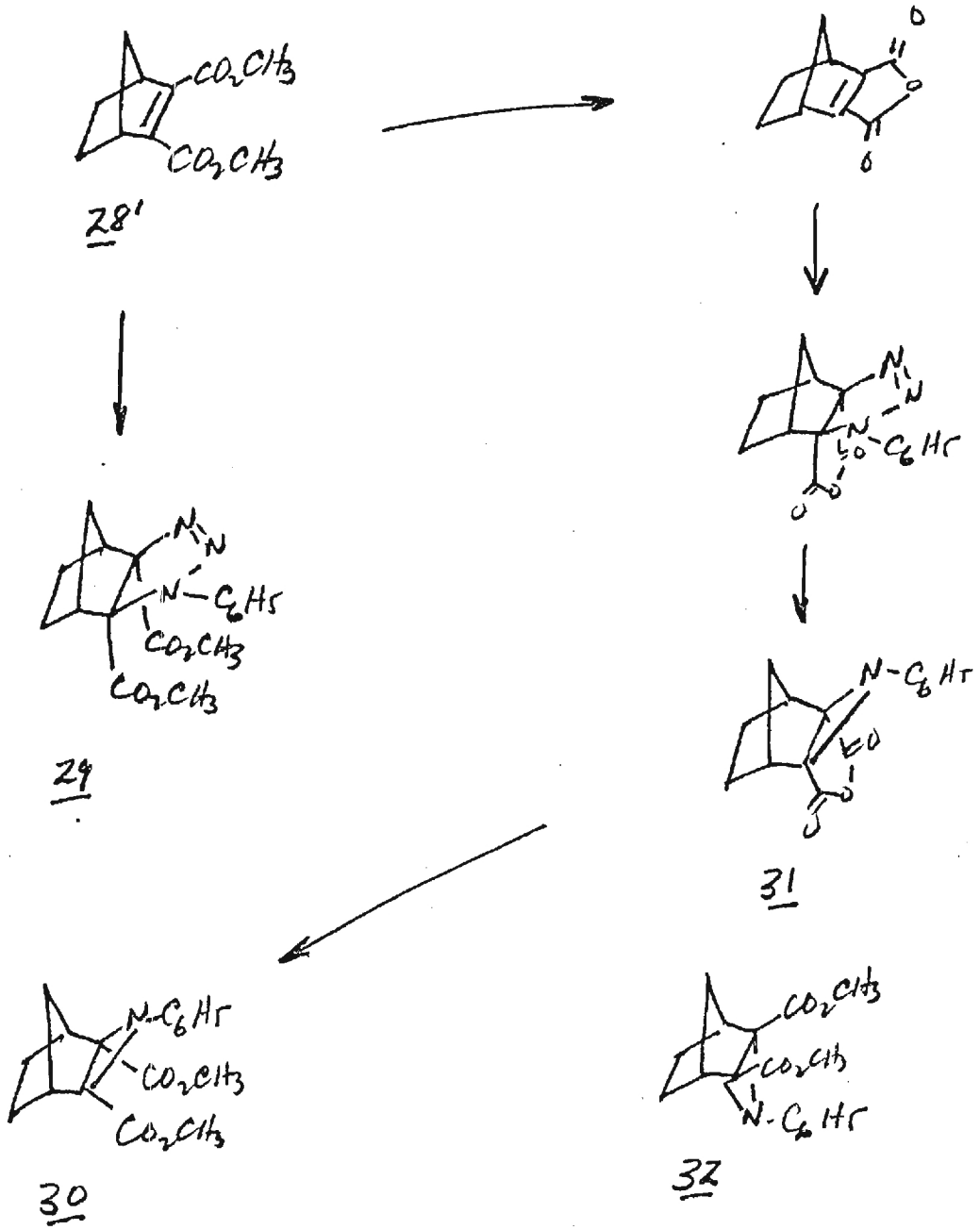


Illustration of Field Effect
Producing High Endo to Exo Ratios

In studies concurrent with the synthesis of the endo triazoline, it was felt desirable that more definitive evidence be provided for the carbon-carbon bond cleavage in the proposed mechanism. Pursuant to this end, the scheme outlined was devised to provide this data and also to provide a study of the chemistry of the 2,6-substituted tricyclic system.

The dimethyl ester 28 reacted with phenyl axide in ethyl acetate and from this mixture was isolated the dimethyl triazoline ester 29. This compound had a melting point of 147-149° and showed an ester band in the



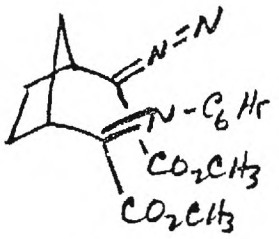
Proposed Scheme for
Providing Evidence of
Carbon-Carbon Bond Cleavage

infrared region at 1740 cm^{-1}. The NMR spectrum ($CDCl_3$) showed five aromatic hydrogens as a multiplet centered at δ7.23, three methoxyl protons as a singlet at δ3.82, three methoxyl protons as a singlet at δ3.50, one bridgehead proton as a multiplet centered at δ3.12, one bridgehead proton as a multiplet centered at δ2.88, two protons in a complex pattern between δ2.60 and δ1.6, two hydrogens as a multiplet centered at δ1.58, and two hydrogens as a multiplet centered at δ1.35. The mass spectrum had no molecular ion, but the highest ion observed was M^+ minus nitrogen. This compound also showed two bands in the ultraviolet region at 298 nm and 285 nm with absorbtivities of 7840 and 7130, respectively. The elemental analysis was consistent with $C_{17}H_{19}N_3O_4$, the formula of triazoline 29.

The triazoline ester (29) was photolyzed in acetone for three hours. G.l.c. analysis showed there was only one product and recrystallization of the photolysis residue gave the exo aziridine 30 (m.p. 106-109°). The infrared spectrum showed an ester band at 1725 cm^{-1} and the mass spectrum showed a molecular ion at m/e 301. The NMR spectrum had five aromatic protons in a complex pattern between δ7.30 and δ6.73, six methoxyl protons as a singlet at δ3.77, two bridgehead protons as a multiplet centered at δ2.77, and six protons in a complex pattern between δ2.20 and δ0.5. The analytical data was consistent with $C_{17}H_{19}NO_4$. In order to correlate the dimethyl aziridine ester (30) with the known aziridine (31), the latter aziridine was treated with diazomethane. Analysis by g.l.c. showed that twenty per cent of the anhydride (31) had been converted to 30.

The last part of the study involved the pyrolysis of the triazoline ester (29). As shown in the Figure, it was visualized that there would be

two products, the exo aziridine (30) and the endo aziridine (32). The results of the pyrolyses of this compound were not as expected and in fact neither aziridine was produced. The triazoline (29) was dissolved in decalin and pyrolyzed for three hours at 162° ± 2°. The decalin was removed in vacuo and the residue chromatographed on silica gel. From this chromatography was isolated a small amount of yellow oil which showed bands in the infrared at 2120, 1720, 1695, and 1630 cm^{-1}. This material decomposed over a period of two hours as evidenced by disappearance of band at 2120 cm^{-1}. Consideration of the proposed mechanism of triazoline decomposition at once leads to the conclusion that the yellow oil was the diazoimine intermediate 33. The infrared spectrum observed was consistent with such a structure.



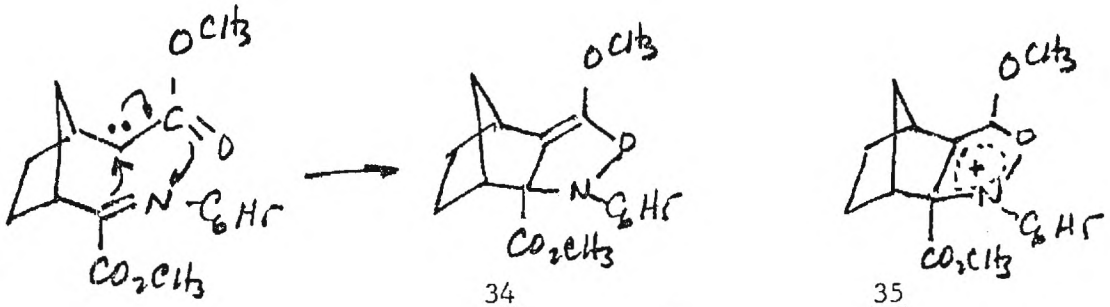
33

The pyrolysis was repeated and as the temperature of the oil bath was slowly increased, infrared spectra were taken periodically until 165° was reached. None of the infrared spectra showed bands between 2200-2100 cm^{-1}, however, a band at 1650 cm^{-1} appeared at 165°. At this temperature the triazoline began to evolve nitrogen. After three hours at 165°, the decalin was removed and the residue was chromatographed on silica gel. Once again the compound with the infrared band at 2120 cm^{-1} was isolated. This compound was placed in freezer until further spectra could be obtained, however upon further investigation this compound had again decomposed (no band at 2120 cm^{-1}). The pyrolysis was again repeated and the products

chromatographed and then the infrared and ultraviolet spectra were taken. The infrared spectrum again showed the band at 2120 cm^{-1} and the UV spectrum showed absorptions at 233, 238, 244, and 251 nm. No definite conclusions could be drawn from the data collected. Further attempts to isolate the oil were abandoned.

Another pyrolysis was carried out as before and the products analyzed by g.l.c. The mixture was found to be 75% of one compound and seven minor products made up the remaining 25%. Mixed injection showed that the exo aziridine was not present in the pyrolysis mixture. The pyrosolate was chromatographed on alumina. Only about 10% of the weight of the residue added to the column was recovered upon elution, and this did not correspond to the major component of the reaction product. The unrecovered material could only be removed by continuous extraction and g.l.c. analysis showed that the major product was no longer present. The major reaction product was also found to decompose upon t.l.c. on silica gel or aluminum oxide. The pyrolysis residue was subjected to preparative g.l.c. and the major component was isolated as a homogeneous yellow oil. The infrared spectrum showed an ester band at 1725 cm^{-1} and a double bond at 1660 cm^{-1}.

Structure 34 is suggested for this compound which could arise as indicated. The mass spectrum of 34 shows a peak at m/e 301 ($M^{+}-N_2$) and



34 35

the next major ion observed is at m/e 286 (26%) which corresponds to loss of a methyl group from m/e 301. Such an ion is not present in the mass spectra of triazoline 29 and aziridine 30 run under identical conditions. The base peak of 34 was observed at m/e 242, presumably due to the stable ion 35. The peak m/e 242 is also the base peak of triazoline 29 but only a small peak (14%) appears at this position in the mass spectrum of aziridine 30. Isoxazoline 34 also shows a peak (30%) at m/e 107 which could correspond to 36, indicating that N and O are bonded together in 34.

36

Such an ion is absent in the spectra of the triazoline 29 and aziridine 30.

Other attempts to again isolate isoxazoline 34 by preparative g.l.c. gave unuseful results and undesirable side effects. The compound as it passed through the g.l.c. and released into the air caused headaches, dizziness and nervousness in persons exposed to it.

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APPENDIX

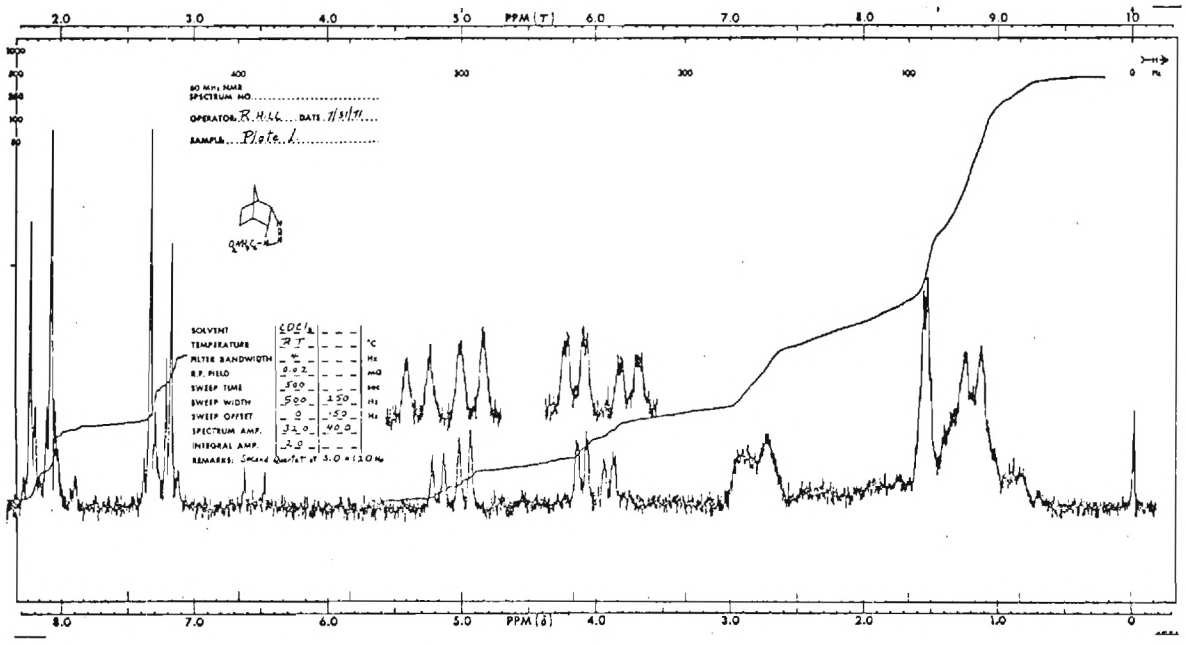

Plate 1. NMR Spectrum of endo Triazoline

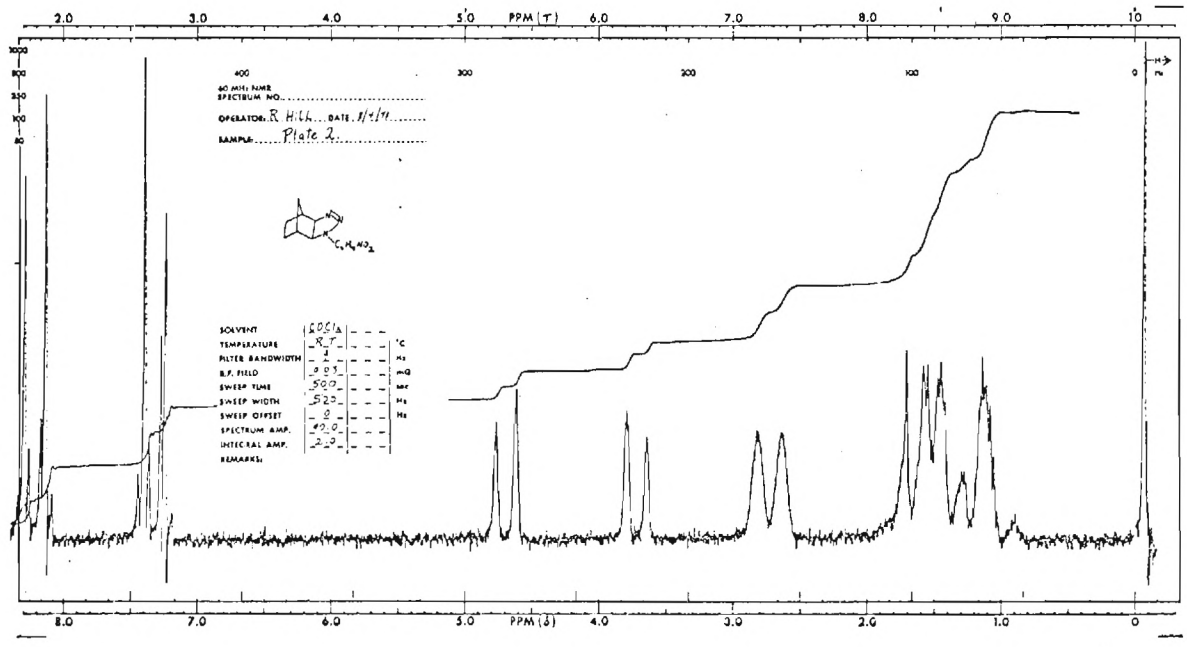

Plate 2. NMR Spectrum of exo Triazoline

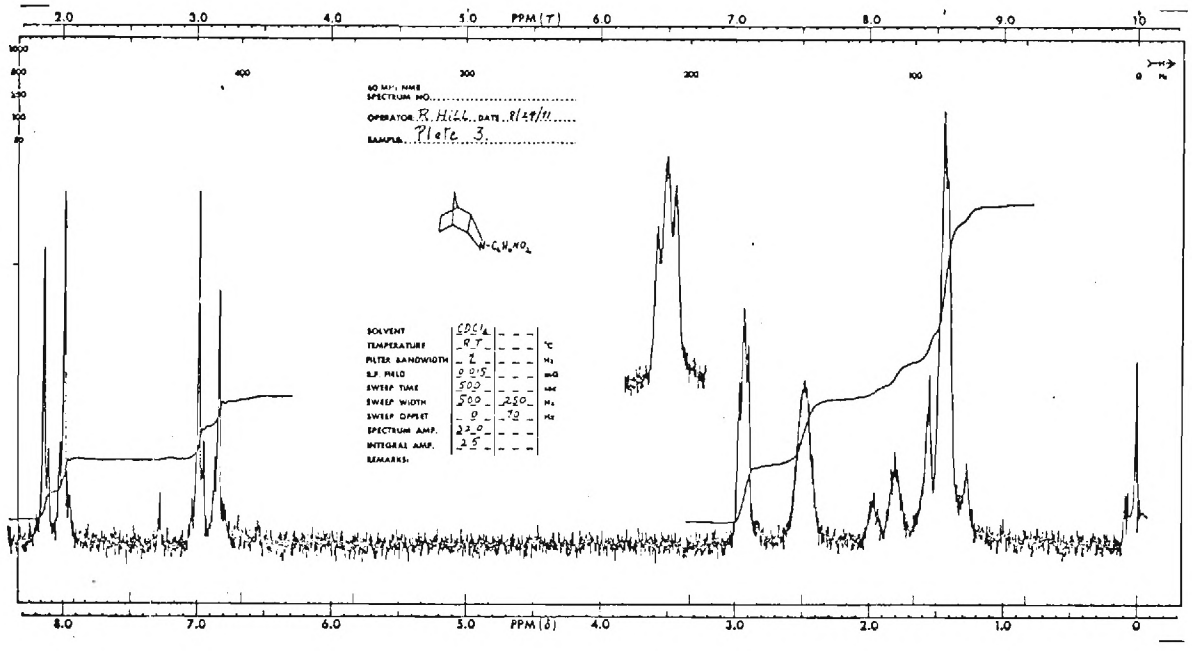

Plate 3. NMR Spectrum of endo Aziridine

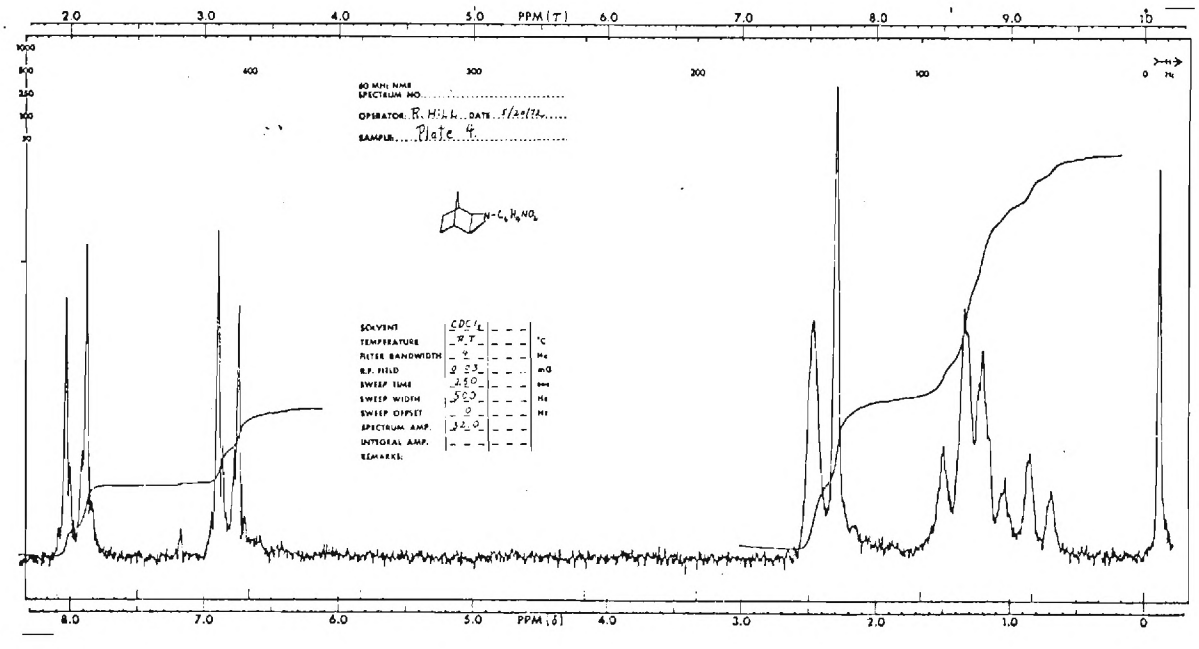

Plate 4. NMR Spectrum of exo Aziridine

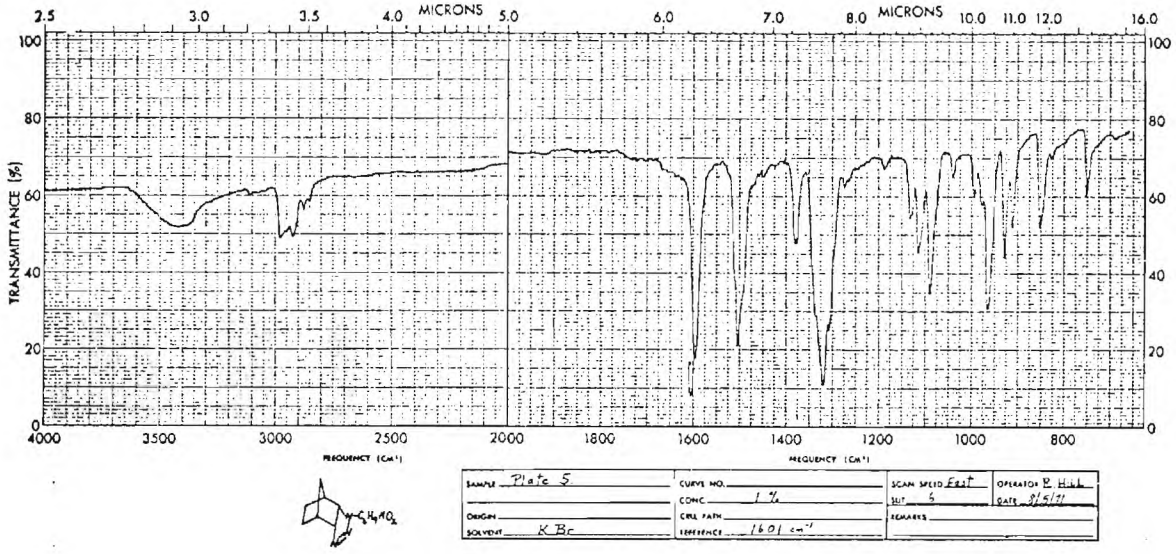

Plate 5. Infrared Spectrum of endo Triazoline

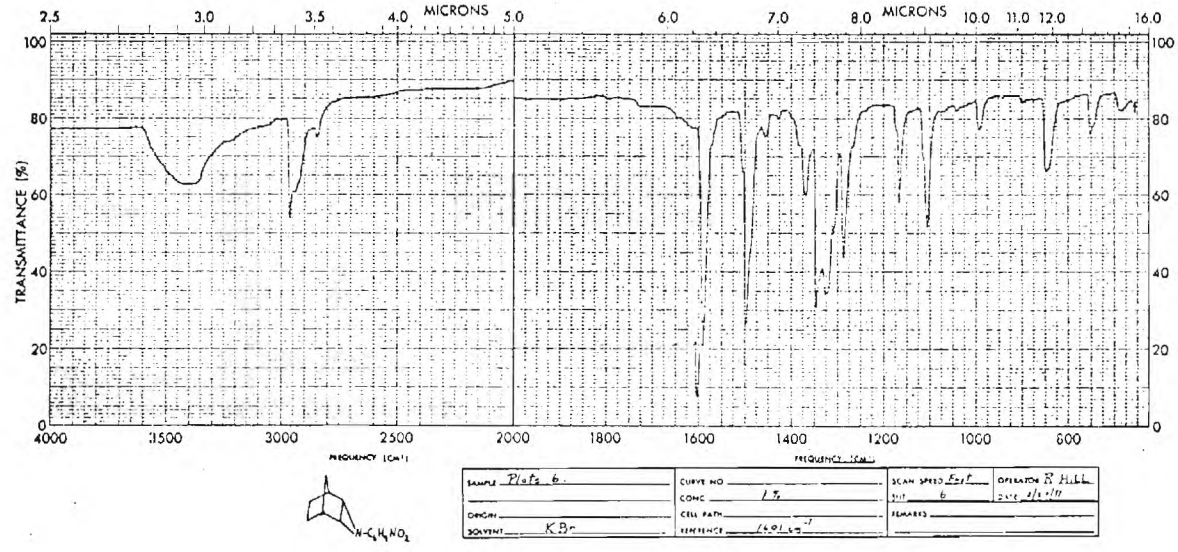

Plate 6. Infrared Spectrum of endo Aziridine

Tetrahedron. Vol. 25, pp. 1393 to 1405. Pergamon Press 1969. Printed in Great Britain

THE REACTION OF BENZENESULFONYL AZIDE WITH *cis–endo* AND *cis–exo* NORBORNENE-5,6-DICARBOXYLIC ACID ANHYDRIDES AND METHYL ESTERS. THE FORMATION OF *endo* AZIRIDINES FROM *exo* TRIAZOLINES[1]

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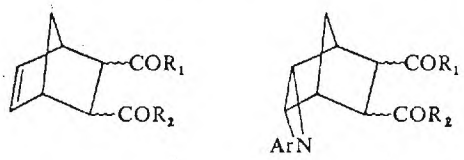
(Received in USA 12 *August* 1968; *Received in the UK for publication* 23 *September* 1968*)*

Abstract—Benzenesulfonyl azide reacts with *cis–endo* (Ia) and *cis–exo*-norbornene-5,6-dicarboxylic anhydrides (IIa) and with the corresponding *cis–exo*-dimethyl ester (IIb) in refluxing carbon tetrachloride to give predominantly *endo* aziridines. Under identical conditions the *cis–endo* dimethyl ester (Ib) gives exclusively the *exo* aziridine and under photolytic conditions the *cis–exo* and *cis–endo* anhydrides and dimethyl esters give almost exclusively *exo* aziridines. At room temperature, the *cis–exo* dimethyl ester IIb gives predominantly the *exo* aziridine, and p-methoxybenzenesulfonyl azide reacts with the *endo*-anhydride Ia in refluxing carbon tetrachloride to give an even greater ratio of the *endo* aziridine. The *exo*-1,2,3-Δ^2-triazoline XIIIa prepared from the *exo* anhydride and phenyl azide, on pyrolysis in decalin, gives an almost 1:1 ratio of the *exo* and *endo* aziridine.

A mechanism is proposed to account for the above observations which involves the conversion of *exo*-1,2,3-Δ^2-triazolines to *endo* aziridines via a 3-diazomethylcyclopentane-2-carboxaldehydeimine intermediate (XI).

IN RECENT reports[2] we have described the thermal reaction of benzenesulfonyl azide with *cis–endo* (Ia) and *cis–exo* norbornene-5,6-dicarboxylic anhydride (IIa) which, in apparent violation of Alder and Stein's[3] "*exo* addition rule" give predominantly *endo*-aziridines IIIa and IVa respectively. The reaction in each case is very clean giving an almost quantitative yield of aziridines. This result is to be contrasted with the



Ia: *endo* anhydride
$R_1 \equiv R_2 = O$
Ib: *endo*-dimethyl ester
$R_1 = R_2 = OCH_3$
IIa: *exo*-anhydride
$R_1 \equiv R_2 = O$
IIb: *exo*-dimethyl ester
$R_1 = R_2 = OCH_3$

III: Ar = ϕSO_2
a: *endo*-anhydride
b: *endo*-dimethyl ester
IV: Ar = ϕSO_2
a: *exo*-anhydride
b: *exo*-dimethyl ester

V: Ar = ϕSO_2
a: *endo*-anhydride
b: *endo*-dimethyl ester
VI: Ar = ϕSO_2
a: *exo*-anhydride
b: *exo*-dimethyl ester

* NSF co-op Graduate Fellow 1965–1966, Rayonier Fellow 1966–1967, American Cyanamid Fellow 1967–1968.

quantitative formation of *exo* aziridine in the reaction of norbornene with benzenesulfonyl azide at room temperature.[4] We have undertaken this more detailed study in order to determine why *endo* aziridines are formed in this case. This expanded study includes the corresponding esters Ib and IIb, the reaction of *p*-methoxybenzenesulfonyl azide and Ia, and the reactions of Ia, Ib, IIa and IIb with benzenesulfonyl azide under photolytic conditions; the results are presented in Table 1. A summary of the evidence supporting the assignment of *exo* or *endo* stereochemistry to the aziridine rings is presented later in the paper.

TABLE 1. *endo/exo* AZIRIDINE RATIO*

Reaction		Aziridine products *endo*	*exo*	Thermal† reaction *endo/exo* aziridine ratio	Photolytic‡ reaction *endo/exo* aziridine ratio
1. ϕSO_2N_3 +	Ia	IIIa +	Va	68/32	6/94
2.	Ib	IIIb +	Vb	<1/>99	<1/>99
3.	IIa	IVa +	VIa	76/24	5/95
4.	IIb	IVb +	VIb	70/30	10/90
5. p-$CH_3OC_6H_4SO_2N_3$ +	Ia	XVIIIb +	XXI	81/5	—

* The ratio of *endo* to *exo*-aziridines was determined by GLC analysis of the product mixtures in the form of the dimethyl esters prepared from the anhydrides by the action of diazomethane in ether–methanol, on an SE 30 on Gas-Chrom Q Column; analysis by NMR gave similar but less accurate results. The pure aziridine products were also isolated for spectral and GLC analysis.[2b] In reaction 5 the thermal reaction ratio represents isolated materials. In this case the *exo* aziridine was not isolated but instead the lactone XXIa, derived from the *exo* aziridine, was isolated in 5% yield.

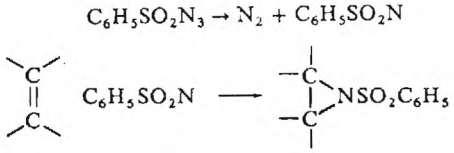
† Carried out by simultaneously refluxing the azide and olefin (1·3:1 molar ratio) samples in carbon tetrachloride for 42 hours. The *endo/exo* aziridine ratio was essentially invariant from 14 to 63 hr. Previously [2b] the total yield of aziridines from Ia and Ib was reported as somewhat less than quantitative but as shown later in this paper the *exo* aziridines Va and Vb are readily transformed into lactones and when this is taken into account the yields of aziridines in these cases are also essentially quantitative.

‡ Carried out by irradiation of the azide-olefin mixtures (1·3:1) at −5° in carbon tetrachloride using a 200 W Hanovia lamp with a Pyrex filter for three hours.

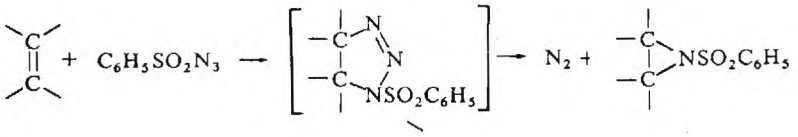
In any consideration of the mechanism of the thermal reaction, one immediately wishes to determine whether the reaction involves nitrene intermediates (Scheme 1-A) or whether the reaction proceeds via a 1,3-dipolar cycloaddition mechanism involving unstable 1,2,3-Δ^2-triazoline intermediates (Scheme 1-B). Benzenesulfonyl azide

SCHEME 1

A.



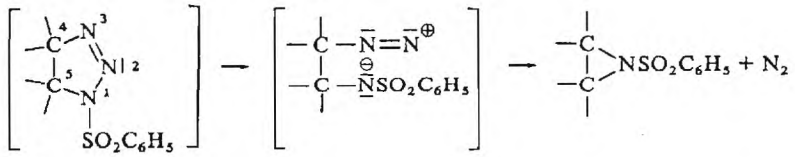
B.



was found not to evolve nitrogen on heating under the thermal reaction conditions in carbon tetrachloride alone or in the presence of dihydro-Ia or dihydro-IIa. Thus a mechanism involving intermediate nitrenes or induced decomposition of the azide by the anhydride moiety is not indicated. Likewise, the fact that diester IIb gives essentially the same ratio of *endo*:*exo* aziridine products as anhydrides Ia and IIa suggests that the anhydride ring plays no unique role as previously thought.[2] Also, the fact that photolysis gives almost exclusively *exo* aziridines further suggests that mechanism A (Scheme 1) is not operable in the thermal reaction.

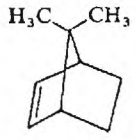
We have discussed previously[4a] the evidence which indicates that the reaction of norbornene with benzenesulfonyl azide proceeds by the now ubiquitous 1,3-dipolar cycloaddition mechanism to give an unstable and yet unisolable 1,2,3-Δ^2-triazoline intermediate. Likewise Huisgen[5] has recently presented evidence which shows that arylsulfonyl azides react with norbornene by a cycloaddition reaction and Bailey and White[6] showed similar results with picryl azides. The instability of the 1,2,3-Δ^2-triazoline ring arises because of the electron withdrawing power of the benzenesulfonyl group which stabilizes the well established[4,5-7] diazonium-betaine inter mediate (Scheme 2). There is no reason to assume a change in mechanism for the

SCHEME 2

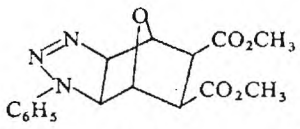


compounds listed in Table 1. As previously reported,[2b] the relative rates of evolution of nitrogen in the thermal reactions with benzenesulfonyl azide are norbornene (100), IIa (10), Ia (1). A similar relative order of reactivity of IIa and Ia has been reported in their epoxidation[8] and is ascribed to a field effect which is greater for the *endo* anhydride because of the closer proximity of the *endo* anhydride group to the double bond. A field effect has also been reported in the reaction of Ia with picryl azide.[6] It is interesting that evidence has recently been presented[9] which suggests a 1,3 dipolar cycloaddition mechanism for peracid epoxidation also.

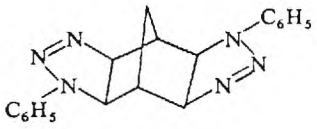
If one accepts that the aziridines produced in the thermal reaction of the olefins listed in Table 1 with benzenesulfonyl azide arise via the unstable 1,2,3Δ^2-triazoline, then the next question is whether the *endo* aziridines arise from *endo* triazolines. This does not seem likely. Alder and Stein first pointed out that azide additions to norbornene systems take place with *exclusive exo* orientation.[2,10,11] These authors also found that what is today referred to as cycloaddition fails if *exo* attack is sterically hindered by substituents at the methylene bridge as in apobornylene (VII). It was



VII



VIII



IX

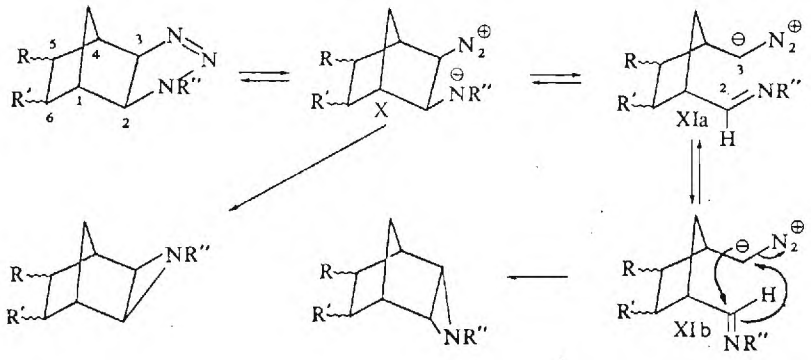
this work that led to the postulation of the "*exo* addition rule" and Huisgen[10] has reported conclusive proof of this selectivity in the reaction of phenyl azide with norbornylene. In spite of the fact that thorough investigations have recently been made of the reaction of norbornene with aryl azides[12] and of 7-oxabicyclo(2.2.1)-heptene derivatives[13] with phenyl azide *no endo* triazolines have been detected. Thus pure crystalline VIII was isolated in 97% yield.[13] Even in the case of norbornadiene, a 96% yield of the *exo*:*exo* bisadduct IX is obtained.[5] It should be noted that in the reaction of norbornadiene with the first molar equivalent of phenyl azide there are no *endo* hydrogens at C-5 and C-6 which could offer steric hindrance to *endo* attack by the azide. Therefore, there seems to be no reason to expect arylsulfonyl azides to react with IIa or IIb from the *endo* side and certainly the *endo* side of Ia and Ib should be extremely hindered. We, therefore, are led to the conclusion that both *endo* and *exo* aziridines arise from *exo* triazolines in the cases under consideration.

A consideration of the requirement for conversion of an *exo*-1,2,3-Δ^2-triazoline to an *endo* aziridine immediately leads to the conclusion that cleavage of the C-4, C-5 bond of the 1,2,3-Δ^2-triazoline ring must occur, followed at some stage by regeneration of this carbon–carbon bond. There is precedence for C—C bond cleavage in the decomposition of 1,2,3-Δ^2-triazolines. Thus, Fusco *et al.*[14] report that the reaction of certain enamines with arylsulfonyl azides results in cleavage of the C-4, C-5 bond of the 1,2,3-Δ^2-triazoline via the diazonium-betaine intermediate (Scheme 2) as indicated in Scheme 3. This fragmentation is particularly facile when R = CR and

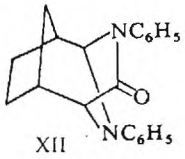
is the basis of the synthesis of α-diazobutyraldehyde (R = CHO, R′ = Et), the first reported aliphatic α-diazoaldehyde.[15] When R and R″ (Scheme 3) are part of the

SCHEME 3

SCHEME 4



same molecular ring system then the diazo and imino groups, because of their close proximity, can react with each other. Thus, the formation of the *endo* aziridines observed in this study could be explained as outlined in Scheme 4. Baldwin *et al.*[16] first proposed the existence of an intermediate such as XIa in order to explain the formation of XII from the pyrolysis of the norbornene-phenyl azide adduct in the presence of phenyl isocyanate.



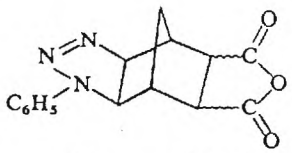
XII

Although the *exo* aziridines could likewise arise via intermediate XI, it does not seem likely that such an intermediate is involved in the reaction of norbornene with benzenesulfonyl azide since, if it were, one would not expect exclusive formation of the *exo* aziridine. In the cases under consideration here (R,R′ = $\overset{O}{\overset{\|}{C}}—O—\overset{O}{\overset{\|}{C}}—$; R = R′ = CO_2Me, Scheme 4), the strong electron-withdrawing groups at C-5 and C-6 would be expected to stabilize the negative charge at C-3 in XI and thus facilitate the formation of this intermediate. The conversion of X into XI would be expected to be less facile at lower temperatures. Indeed, we have observed that in the reaction of IIb with benzenesulfonyl azide, the *endo*:*exo* aziridine ratio drops to 30:70 at room temperature; under these conditions, as expected, the rate of reaction is very low. This observation is consistent with the preponderant formation of *exo* aziridines via intermediate X.

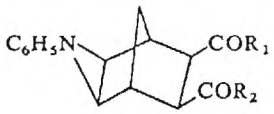
An examination of the thermal reaction data in Table 1 shows that Ib is clearly different in its behavior from Ia, IIa, and IIb. We believe the low *endo*:*exo* aziridine ratio observed for Ib is a result of steric inhibition and unfavorable entropy, which results in a low population of the conformer XIb, the intermediate for *endo* aziridine formation.* The preponderant formation of *endo* aziridines from Ia, IIa and IIb (Table 1) is more difficult to explain. This may be an indication of the greater stability of XIb relative to XIa, in these cases, because of the eclipsing of the groups at C-2 and C-3 in XIa.

In order to obtain additional evidence in support of the mechanism outlined in Scheme 4 we investigated the pyrolysis of a stable *exo*-1,2,3-Δ^2-triazoline, namely XIIIa, prepared by the reaction of IIa and phenyl azide. The exo anhydride IIa was chosen instead of the endo anhydride Ia when it was found that the anhydride ring participated in the thermal reaction of the adduct from Ia. The thermolysis of XIIIa was found to be greatly influenced by the nature of the solvent; thus heating XIIIa in diethylene glycol diethyl ether led to a complex mixture, whereas heating in decalin at 160 ± 5° gave only aziridines XIVa and XVa in a ratio of 46:54. *exo*

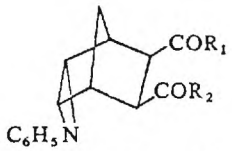
* *A priori*, it does not appear likely that the formation of *endo* aziridine from XIb should be substantially faster than *exo* aziridine formation from X or XIa hence this is not a violation of the Curtin–Hammett principle.



XIII a: *exo* anhydride
b: *endo* anhydride



XIV a: $R_1 \equiv R_2 = O$
b: $R_1 = R_2 = OCH_3$



XV a: $R_1 \equiv R_2 = O$
b: $R_1 = R_2 = OCH_3$

Aziridine XIVa and its dimethyl ester XIVb, prepared by treatment of XIVa with diazomethane in ether–methanol, showed identical physical properties with those previously reported for these compounds.[2,17] The previously unreported *endo* aziridine XVa showed the characteristic aziridine absorption[18] in the infrared (1200 cm^{-1}) and was readily converted into the corresponding dimethyl ester which showed similar aziridine absorption (1195 cm^{-1}).

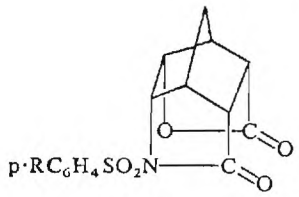
That XVb, and therefore XVa, contained an *endo* aziridine ring was apparent from its NMR spectrum. Thus the *exo* protons at C-2 (H_2) and C-3 (H_3) gave an ill-defined triplet at δ 2·80 with a half-height width ($W_{\frac{1}{2}h}$) of 6 c/s which was superimposed on the signal arising from the bridgehead protons ($H_1 + H_4$) in $CDCl_3$. However, in benzene the two signals were clearly separated. The width of the H_2, H_3 signal is clearly indicative of *exo* protons and therefore of an *endo* aziridine ring as shown in Table 2. Thus *endo* aziridines IIIb and IVb show a similar broad signal for the H_2, H_3

TABLE 2. NMR SPECTRA OF AZIRIDINES

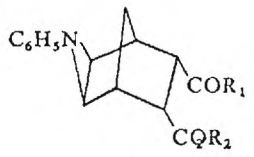
Compound	Half-height width of H_2, H_3 signal	$\delta_{7\,anti}$	$\delta_{7\,syn}$
Vb	2·5 ± 0·5	0·90	1·70
VIb	2·5 ± 0·5	1·47	1·75
XVIIb	2·5 ± 0·5	0·84	1·92
XIVb	2·5 ± 0·5	1·73	1·73
IIIb	6·5 ± 0·5	2·00	1·53
IVb	6·5 ± 0·5	2·32	1·92
XVb	6·5 ± 0·5	2·28	1·82
XVIIIa	6·0 ± 0·5	2·07	1·71
XVIIIb	6·0 ± 0·5	1·85	1·44

* All spectra except for those of XVIIb and XVIIIa, which were run in DMSO, were run in $CDCl_3$.

protons (Table 2). The structure of IIIa and therefore IIIb has been well established[2a] by its conversion to XVI. Likewise the structure of IVa, and therefore IVb, is known since the former has been chemically degraded to the 2-*endo* benzenesulfonamidobicyclo(2.2.1)heptane.[2] By contrast, the isomeric *exo* aziridines Vb, VIb and XIVb show narrow signals for H_2, H_3 with $W_{\frac{1}{2}h}$ 2·5 ± 0·5 c/s (Table 2), which are known to be characteristic of *exo* aziridines.[2,4] As an additional example, *exo* aziridine XVIIb was prepared by addition of phenyl azide to anhydride Ia to give the known *exo* triazoline[11] XIIIb which was photolyzed to give the previously reported[11] *exo*



XVI: R = H
XX: R = OCH_3

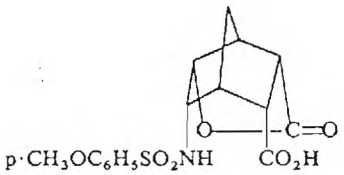


XVII a: $R_1 \equiv R_2 = O$
b: $R_1 = R_2 = OCH_3$

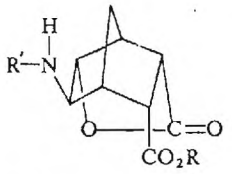
XVIII a: $R_1 \equiv R_2 = O$
b: $R_1 = R_2 = OCH_3$

aziridine XVIIa which in turn was treated with diazomethane to give the known[11] XVIIb. Alder and Stein[11] also prepared XVIIb by a similar route, but using pyrolysis rather than photolysis to convert the triazoline to the aziridine. Scheiner[19] has shown that photolysis of 1,2,3-Δ^2-triazolines yields aziridines in excellent yields with a negligible amount of rearrangement. As indicated in Table 2, XVIIb shows the characteristic narrow signal for H_2, H_3 observed in *exo* aziridines. Tori[18] has shown that an *exo* aziridine produces an anisotropic shielding effect on the 7-*anti* proton in a norbornyl system and this effect can be used to assign *exo* or *endo* configuration to an aziridine ring. This shielding is illustrated by Vb and XVIIb in Table 2, where the 7-*anti* protons appear 0·8–1·1 ppm upfield from the 7-*syn* protons. However this method cannot be used with VIb and XIVb since these substances contain C-2 and C-3 *exo* carbomethoxy groups which deshield the 7-*anti* protons.

The reaction of Ia with *p*-methoxybenzenesulfonyl azide under the previously described thermal reaction conditions led to an 81% yield of the *endo* aziridine XVIIIa which was converted into the corresponding dimethyl ester XVIIIb. The NMR spectra of XVIIIa and XVIIIb are consistent with the assignment of *endo* configurations to the aziridine rings of XVIIIa and XVIIIb as indicated in Table 2. That XVIIIa did indeed contain an *endo* aziridine ring was shown by its conversion in sodium hydroxide to XIX as previously described for IIIa[2a] and pyrolysis of XIX gave XX. In addition to XVIIIb, there was obtained on chromatography of the crude



XIX



XXIa: R′ = $CH_3OC_6H_4SO_2$, R = CH_3
b: R′ = $C_6H_5SO_2$, R = CH_3
XXIIa: R′ = C_6H_5, R = H
b: R′ = C_6H_5, R = CH_3

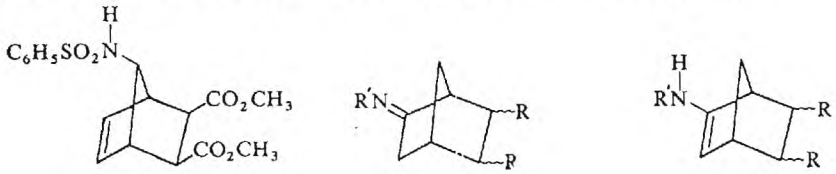
methylated product from the reaction of Ia with *p*-methoxybenzenesulfonyl azide, a 5% yield of XXIa, which undoubtedly arises from the *exo* aziridine, which was not isolated. Similarly, in the thermal reaction of Ib with benzenesulfonyl azide a corresponding lactone (XXIb) was formed on prolonged refluxing of the reaction mixture. Thus after 42 hr reflux the ratio of the lactone to *exo* aziridine was 0·46 : 1 while after

63 hr the ratio had increased to 1·25 : 1. Likewise, in the photolysis of Ib and benzenesulfonyl azide, large amounts of lactone XXIb were isolated if the reaction products were not isolated immediately and the pyrolysis of XIIIa in diethylene glycol diethyl ether gave lactone XXIIa.

The effect of solvent in the pyrolysis of XIIIa and the increase in *endo* : *exo* aziridine ratio in the reaction of Ia with *p*-methoxybenzenesulfonyl azide provide additional support for the mechanism proposed in Scheme 4. Thus, a non-polar solvent such as decalin would favor less charge separation as in XI and thus facilitate the conversion of X to XI and hence increase the amount of *endo* aziridine produced. The electron-releasing methoxy group should destabilize X and thus also favor XI.

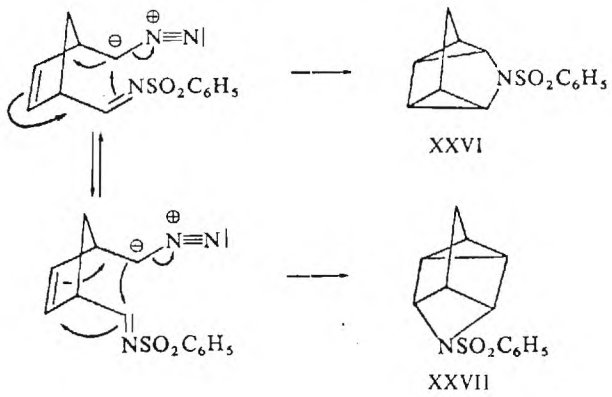
The photolytic reaction can be visualized as occurring by one of three pathways: (1) an initial thermal addition of azide to give preferentially *exo* triazoline, followed by photochemical decomposition to yield *exo* aziridine; (2) photochemical addition of azide to give *exo* triazoline followed by photochemical decomposition to yield *exo* aziridine; (3) photochemical generation of a nitrene followed by reaction with the alkene from the less hindered *exo* side to give *exo* aziridine. The first possibility is eliminated because the reaction is much too fast to involve initial thermal 1,2-dipolar cycloaddition (Table 1). With the evidence available at present, it is not possible to state with certainty whether the photochemical reaction proceeds by pathway (2) or (3) but the isolation of an insertion product, presumed to be XXIII, lends support to pathway (3). The photodecomposition of *exo* 1,2,3-Δ^2-triazolines is known to lead to almost exclusive formation of *exo* aziridines.[4, 5, 19, 20]

It is interesting that in the pyrolysis of XIIIa in decalin and in the reactions of I and II with benzenesulfonyl azide and the reaction of Ia with *p*-methoxybenzenesulfonyl azide, no imines such as XXIV were observed. This is to be contrasted with the results of Oehlschlager[21] in the pyrolysis of the triazoline adduct formed in the reaction of norbornene with phenyl azide. The latter workers have observed that the amount of imine increases in more polar solvents. Thus, the imine may be produced by loss of nitrogen from an intermediate such as X to give a carbonium ion followed by proton transfer from C-2 to the nitrogen anion X to give an enamine type structure XXV which could equilibrate to XXIV.[22] Such a process would be more facile in more polar solvents and would be hindered by electron-withdrawing groups (R in XXIV) such as the anhydride moiety and carbomethoxy groups on the norbornyl ring system. Likewise, Oehlschlager, *et al.* observed rearranged products such as *syn*-7-N-phenylaminobicyclo(2.2.1)hept-2-ene and 3-N-phenylaminotricyclo(2.2.1.$0^{2,6}$)-heptane which were not observed in those examples mentioned in this study and which could arise via the above mentioned carbonium ion mechanism.



XXIII XXIV XXV

The mechanism proposed in Scheme 4 readily accounts for the minor product reported by Franz and Osuch[23] in the reaction of norbornadiene with benzenesulfonyl azide regardless of whether this product possesses structure XXVI or XXVII.



XXVI

XXVII

Finally, the work of Oehlschlager and McDaniel,[21] who have independently observed the conversion of *exo* triazolines to *endo* aziridines, further supports the mechanism shown in Scheme 4. In thier work, which involved the triazoline adduct from norbornene and phenyl azide, the *endo* aziridine was only a minor product (a maximum of 9% in decalin). This is consistent with the decreased stability of XI in the absence of electron-withdrawing groups (R,R′ Scheme 4) on the norbornyl ring.

EXPERIMENTAL

M.ps were taken on a Thomas–Hoover apparatus and are uncorrected. IR spectra were recorded with a Perkin–Elmer 237B spectrophotometer. NMR spectra were obtained with a Varian A-60 spectrometer using $CDCl_3$ as solvent and TMS as an internal standard ($\delta = 0$). Gas chromatographs were obtained using an F & M Biomedical Gas Chromatograph model 400 containing glass columns and a hydrogen flame detector. Photolyses were performed using a Hanovia 200 W lamp with a Pyrex filter.

Thermal reaction of benzenesulfonyl azide with bicyclo {2.2.1} 5-*heptene*-endo–cis (Ia) *and* exo–cis (IIa)-*anhydrides and dimethyl esters* (Ib *and* IIb). Benzenesulfonyl azide was prepared as previously described.[24] The *endo* anhydride Ia (m.p. 163–165°) was obtained commercially (Eastman) while the *exo* anhydride IIa (m.p. 142–144°) was prepared by the method of Craig.[25] The corresponding dimethyl esters Ib and IIb were prepared by treatment of methanol solns of the anhydrides with ethereal diazomethane. The four reactions were run simultaneously under identical conditions (6·1 mmoles of olefin and 8·2 mmoles of benzenesulfonyl azide in 20 ml CCl_4 refluxed on the steam bath). After addition of chloroform to dissolve precipitated products, samples were analyzed by gas chromatography using a 0·125-in diam by 4-ft long glass column of 3·8% SE-30 on 80/100 mesh Diatoport S at a column temp of 238° and a He flow rate of 80 cc/min. The anhydride reaction mixtures were treated with MeOH and ethereal diazomethane prior to analysis to convert the anhydrides to dimethyl esters. Authentic samples for comparisons were obtained as previously described[2] and gave the following retention times under the conditions specified above: IIIb, 2·7 min; IVb, 4·3 min; Vb, 5·1 min; VIb, 5·9 min. The ratios of *endo* to *exo* aziridine products after 42 h are given in Table 1. The ratios were determined by measuring GLC peak areas with a planimeter.

While Ia, IIa and IIb gave only *endo* and *exo* aziridines in a ratio of between 2 and 3:1, Ib gave almost exclusively *exo* aziridine Vb in the early stages of the reaction. In addition, a third product (XXII) was observed, with a GLC retention time of 7·2 min which increased as the reaction proceeded. At 42 hr the ratio XXII:Vb was 0·46 and after 63 hr the ratio had increased to 1·25, i.e. XXII was the major product. After 24 months at room temp the conversion of Vb to XXII was complete; crystallization of this solid product from acetone gave pure XXII in essentially quantitative yield. The analytical sample was obtained after recrystallizationn from acetone and gave m.p. 167–169°. (Found: C, 54·44; H, 4·63. Calc. for $C_{16}H_{17}O_6NS$: C, 54·5; H, 5·23%); ν_{max}^{KBr} 3230, 1780, 1730 cm^{-1}; NMR (d_6-acetone) δ 1·70 (d, $J = 12$ c/s, 1H), δ 2·10 (d, $J = 12$ c/s, 1H), δ 3·54 (s, 3H), δ 3·93 (m, 1H), δ 4·60 (d, $J = 5$ c/s, 1H), δ 7·5–8·03 (m, 5H).

Reaction of benzenesulfonyl azide with exo-*dimethyl ester* IIb *at room temp.* Dimethyl ester IIb (1·28 g) and the azide 1·5 g) were dissolved in 20 ml CCl_4 in a flask protected from the light by Al foil. The reaction was left standing at room temp and N_2 was slowly evolved. After 4 weeks, a considerable amount of crystalline solid had formed and filtration gave 0·4 g of *exo* aziridine VIb, m.p. 147–149°. The solvent was then removed *in vacuo* at room temp to give 2·1 g of a gummy residue. Chromatography on alumina of 1·6 g of this material gave in the benzene eluate (850 ml), 0·21 g of a mixture of the starting materials and in the chloroform:benzene (1:1) eluate (125 ml) 0·31 g of solid material which was found by GLC analysis (6-ft by 0·125-in column of 10% SE-30 on 100/120 mesh Gas-Chrom Q at 250° and He flow of 110 ml/min) to contain 36% *exo* aziridine VIb and 63% *endo* aziridine IVb. Elution with 125 ml chloroform gave 0·15 g of solid consisting of 73% VIb and 24% IVb. Elution with an additional 375 ml of chloroform gave 0·02 g of pure VIb. Calculation then gives an *endo*:*exo* aziridine ratio of 30:70.

Photolytic reaction of benzenesulfonyl azide with bicyclo{2.2.1} *5-heptene*-endo–cis (Ia) *and* exo–cis (IIa)-*dicarboxylic anhydrides and dimethyl esters* (Ib *and* IIb). The four reactions were run simultaneously by dissolving the reactants (6·1 mmoles of olefin and 8·2 mmoles of azide) in 50 ml CCl_4, cooling the solns to −5° (whereupon the olefins partially precipitated), and irradiating for 3 hr with a Pyrex-filtered 200 W Hanovia lamp. The reaction mixtures, in the case of the anhydrides, were then treated with MeOH and ethereal diazomethane and analyzed on a 0·125 in by 6 ft glass column of 2% SE-30 on 60/80 mesh Gas-Chrom Q at 238° and a He flow rate of 80 ml/min. The ratios of *endo* to *exo* aziridine products are reported in Table 1. In each case the *exo* aziridine was formed almost exclusive of the *endo* aziridine. In the reactions of the olefins containing *endo* carbonyl functions (i.e. Ia and Ib) the major product was not the *exo* aziridine but XXII formed from the *exo* aziridine. In the reaction of IIa a considerable amount of insertion product XXIII was also formed. The isolation of XXIII is described below.

Photolysis of benzenesulfonyl azide with anhydride IIa *in ethyl acetate*; *isolation of the insertion product* XXIII. Azide (18·3 g, 0·1 mole) was added to a soln of 16·4 g (0·1 mole) of IIa in 500 ml EtOAc. The resulting soln was cooled to 0°, deoxygenated by bubbling dry N_2 through it, and irradiated for 6 hr during which time a considerable amount of black tarry material precipitated. The solvent was removed on the rotary evaporator to give 33·6 g of a dark syrup which was dissolved in MeOH and esterified with ethereal diazomethane. After evaporation of solvent, the residue was chromatographed on Merck acid-washed alumina. Elution with 200 ml of benzene gave about 10 mg of a yellow oil which showed no carbonyl or azide absorptions in the IR. Elution with an additional 500 ml benzene and 5 l of 1:1 benzene:chloroform gave 12·54 g of a solid which was recrystallized from ether to give 10·3 g of *exo* VIb (m.p. 148–149°) identical with that previously reported.[2] Analysis of the mother liquor by GLC showed the presence of *endo* IVb and the insertion product XXIII in addition to VIb. Elution with 1·2 l. chloroform gave 4·3 g material. Rechromatography of this material on silica gel and crystallization from acetone of the chloroform eluate gave 290 mg of XXIII. The analytical sample was obtained by recrystallization from acetone and gave m.p. 142–143°. (Found: C, 55·68; H, 5·40. Calc for $C_{17}H_{19}O_6NS$: C, 55·94; H, 5·25%); ν_{max}^{KBr} 3280, 1740, 1715 cm^{-1}; NMR ($CDCl_3$) δ 2·97 (S, $W_{\frac{1}{2}h}$ 6 c/s, 2H), δ 3·25 (S, $W_{\frac{1}{2}h}$ 5·5 c/s, 2H), δ 3·50 (d, J = 9·5 c/s, 1H, collapses to broad singlet on addition of D_2O), δ 3·54 (S, 3H), δ 5·42 (d, J = 9·5 c/s, 1H, disappears on addition of D_2O), δ 6·12 (S, 2H), δ 7·4–7·9 (m, 5H).

Preparation and pyrolysis of the phenyl azide adduct of exo *anhydride* IIa. Phenyl azide was prepared from phenylhydrazine and nitrous acid as described in the lit.[26] The azide (6 g) was added to a soln of IIa (8·2 g) in 250 ml CCl_4 and the mixture was refluxed on the steam bath for 3 hr during which time XIIIa (11 g, 79%) precipitated as a white powder, m.p. 95–96° (lit.[11] 220° dec) ν_{max}^{KBr} 1850, 1770, 1600 cm^{-1}. Triazoline XIIIa (14·2 g) was added to 500 ml of dry, freshly distilled diethylene glycol diethyl ether (Eastman) and the mixture was placed in an oil bath at 160 ± 5°. As the mixture warmed, the solid dissolved and vigorous evolution of N_2 occurred. After 30 min, the rate of gas evolution was very low and heating was discontinued. The soln was evaporated on the steam bath at 0·05 mm to a volume of about 150 ml and cooled to room temp, whereupon 4·12 g of the *exo* XIVa crystallized. Recrystallization from acetone gave a sample, m.p. 217–219° (lit[3] 219°) which was shown by IR spectra and GLC to be identical with XIVa obtained by pyrolysis of XIIIa in decalin as described below. The mother liquor was examined by GLC and found to be a very complex mixture and was not further investigated.

Triazoline XIIa (11 g) was added to 500 ml of freshly distilled decalin (Eastman) and heated in an oil bath at 160 ± 5° for 3·3 hr. The mixture had not become homogeneous and 3·2 g of starting material was filtered from the hot reaction mixture. The filtrate was analyzed by GLC using a 0·125 in by 6 ft glass column of 10% SE-30 on 100/120 mesh Gas-Chrom Q at 173° and a He flow rate of 93 cc/min. Under these conditions, two peaks only were observed at retention times of 12·3 min (54%) and 13·4 min (46%). After standing

in the refrigerator 48 hr a solid (6·83 g) had crystallized and was filtered. The filtrate was evaporated at 32° and 0·025 mm to give an additional 0·46 g of solid. A portion (2·4 g) of the combined solids was fractionally crystallized from acetone. The first crystals were pure *exo* XIVa which had a retention time of 13·4 min under the conditions described above. The analytical sample was obtained by recrystallization from acetone and gave m.p. 218–220° (Found: C, 70·59; H, 5·09. Calc. for $C_{15}H_{13}O_3N$: C, 70·65; H, 5·14%); ν_{max}^{KBr} 1848, 1775, 1231 cm^{-1}. After several fractions were crystallized as mixtures the residue left upon evaporation of the mother liquor was *endo* XVa with a GLC retention time of 12·3 min. The analytical sample was obtained by recrystallization from acetone and gave m.p. 165–167°. (Found: C, 69·75; H, 5·00. Calc. for $C_{13}H_{15}O_3N$: C, 70·65; H, 5·14%; ν_{max}^{KBr} 1860, 1785, 1200 cm^{-1}. Treatment of a MeOH soln of 4·4 g of the solid reaction product with ethereal diazomethane followed by fractional crystallization from hexane resulted in the isolation of XIVb and XVb. Esterification of the pure XIVa and XVa also gave XIVb and XVb, respectively. The analytical sample of XIVb was obtained by recrystallization from hexane and gave m.p. 134–136° (lit.[3] 138°) (Found: C, 67·61; H, 6·35. Calc. for $C_{17}H_{19}O_4N$: C, 67·83; H, 6·36%); ν_{max}^{KBr} 1733, 1208 cm^{-1}; NMR ($CDCl_3$) δ 1·73 (S, $W_{\frac{1}{2}h}$ 5 c/s, 2H), δ 2·34 (S, $W_{\frac{1}{2}h}$ 2·5 c/s, 2H), δ 2·73 (S, $W_{\frac{1}{2}h}$ 3 c/s, 2H), δ 2·91 (S, $W_{\frac{1}{2}h}$ 4 c/s, 2H), δ 3·67 (S, 6H), δ 6·7–7·4 (m, 5H). The analytical sample of XVb was obtained by recrystallization from hexane and gave m.p. 87–89°. (Found: C, 67·66, H, 6·42. Calc. for $C_{17}H_{19}O_4N$: C, 67·83; H, 6·36%); ν_{max}^{KBr} 1744, 1195 cm^{-1}, NMR ($CDCl_3$) δ 1·83 (d, J = 10 c/s, 1H), δ 2·27 (d, J = 10 c/s, 1H), δ 2·78 (S, 2H), overlapping half of triplet (J = 2 c/s, 2H) at δ 2·81, δ 3·12 (d, J = 1·6 c/s, 2H), δ 3·60 (S, 6H), δ 6·8–7·4 (M, 5H); NMR (C_6H_6) δ 2·42 (m, $W_{\frac{1}{2}h}$ 6·5 c/s), δ 2·58 (m, $W_{\frac{1}{2}h}$, 4·5 c/s).

Preparation and pyrolysis of the phenyl azide adduct XIIIb *of* endo *anhydride* Ia. Phenyl azide (11·9 g, 0·1 mole) was added to a soln of 16·4 g (0·1 mole) of Ia in 200 ml EtOAc and stirred at room temp. The *exo* XIIIb precipitated as the reaction proceeded and was filtered after 19 days to give 17·9 g of XIIIb, m.p. 232–234° dec. (lit.[27] 225 dec); ν_{max}^{KBr} 1860, 1780, 1600 cm^{-1}.

Pyrolysis of XIIIb in diethylene glycol diethyl ether (Eastman) at 160 ± 5° for 2 hr gave a complex mixture from which four unidentified crystalline products have been isolated by chromatography on alumina. In addition, two other products crystallized directly from the reaction mixture upon concentration. One of these, isolated in 7·5% yield, has been identified as XXIIa. The analytical sample was obtained by recrystallization from acetone and gave m.p. 233–235° (lit.[11] 236°). (Found: C, 66·16; H, 5·70. Calc. for $C_{15}H_{15}O_4N$: C, 65·93; H, 5·49%); ν_{max}^{KBr} 3400, 2800–3650 (broad), 1780, 1700 cm^{-1}. Treatment of MeOH soln of XXIIa with ethereal diazomethane gave the ester XXIIb, m.p. 208–210° (lit.[11] 204); ν_{max}^{KBr} 3395, 1776, 1726 cm^{-1}. None of the compounds isolated were aziridines. The structures of the other five products are currently under investigation.

In order to prepare the *exo* XVIIb 4·3 g of XIIIb was suspended in 500 ml EtOAc and irradiated at 16° for 2·5 hr with a Hanovia 200 W lamp fitted with a quartz filter. The soln was then concentrated, whereupon 2·04 g (84%) of XVIIa crystallized as fine white platelets, m.p. 160–162°; ν_{max}^{KBr} 1860, 1780, 1220 cm^{-1}. Treatment of XVIIa with ethereal diazomethane and MeOH followed by evaporation of the solvent and recrystallization of the residue from ether gave XVIIb, m.p. 83–84° (lit.[11] 86°): NMR (CCl_4) δ 0·84 (d, J = 11 c/s, 1 HO, δ 1·92 (d, J = 11 c/s, 1H), δ 2·78 (S, $W_{\frac{1}{2}h}$, 2·5 c/s, 2H), δ 2·87 (S, $W_{\frac{1}{2}h}$ 5 c/s, 2H), δ 2·98 (S, $W_{\frac{1}{2}h}$ 3·5 c/s, 2H), δ 3·62 (S, 6H), δ 6·7–7·3 (m, 5H). After standing 24 months this solid material was analyzed by GLC and found to have undergone a significant (40%) change to XXIIb. Recrystallization from CH_2Cl_2 gave crystalline XXIIb, m.p. 208–210° (no depression on admixture with XXIIb obtained in the pyrolysis of XIIIb). These compounds also showed identical retention times by GLC (6·7 min on a 6-ft by 0·125-in column of 3% SE-30 on 100/120 mesh Gas-Chrom Q at 210° and a He flow of 95 ml/min) and gave identical IR spectra. Analysis by GLC of the mother liquor after four days at room temp gave only one peak corresponding to XXIIb. The NMR (d_6-acetone) of XXIIb was very similar to that of XXIb showing peaks at δ 1·76 (d, J = 11 c/s, 1H), δ 2·26 (d, J = 11 c/s, 1H), δ 3·69 (S, 3H), δ 4·00 (m, 1H), δ 4·52 (d, J = 5 c/s, 1H), δ 6·5–7·4 (m, 5H).

Reaction of p-*methoxybenzenesulfonyl azide with anhydride* Ia. The azide was prepared by addition of an acetone soln of *p*-methoxybenzenesulfonyl chloride (Aldrich) to aqueous sodium azide according to the published procedure for *m*-nitrobenzoyl azide.[28] The azide was purified by recrystallization from methanol and gave m.p. 50–55° (lit.[29] 49–51°); ν_{max}^{KBr} 2340, 2130, 1580 cm^{-1}; NMR (CCl_4) δ 7·42 (d, J = 8·5 c/s, 2H), δ 6·60 (d, J = 8·5 c/s, 2H), δ 3·52 (S, 3H). The azide (4 g, 18·8 mmoles) and anhydride Ia (3 g, 18·3 mmoles) were dissolved in 100 ml CH_2Cl_2 and stirred at room temp. After 60 hr no apparent reaction had occurred (no decrease in intensity of azide band in IR) and the soln was then refluxed on the steam bath 56 hr. Upon cooling to room temp, 3·61 g of XVIIIa (m.p. 200–210°) crystallized. Concentration of the filtrate to about ½ its volume led to crystallization of an additional 1·39 g (m.p. 220–224°). The combined solids were re-

crystallized from CH_2Cl_2 to give the analytical sample of XVIIIa, m.p. 226–228°. (Found: C, 55·04; H, 4·46. Calc. for $C_{16}H_{15}O_6NS$: C, 55·01; H, 4·30%): ν_{max}^{KBr} 1845, 1775, 1155, 1310, 1325 cm^{-1}; NMR (d_6, —DMSO) 1·71 (d, J = 9 c/s, 1H), δ 2·07 (d, J = 9 c/s, 1H), δ 2·72 (S, $W_{\frac{1}{2}h}$ 7 c/s, 2H),δ 3·23 (S, $W_{\frac{1}{2}h}$, 6 c/s, 2H), δ 3·43 (S, $W_{\frac{1}{2}h}$ 6 c/s, 2H), δ 3·58 (S, 3H). δ 6·59 (d, J = 8 c/s, 2H), δ 7·17 (d, J = 8 c/s, 2H). The filtrate was evaporated and the residue dissolved in MeOH and treated with ethereal diazomethane. After evaporation of the solvent 3·0 g of a yellow gum was obtained which was then chromatographed on Merck acid-washed alumina (activity III). Elution with 0·25 l. benzene gave 0·2 g oil which could not be crystallized. Further elution with 1·25 l. benzene gave a fraction (0·5 g) which was crystallized from ether to give 0·35 g of XVIIIb (m.p. 191–192°) identical (m.p., IR spectra) to XVIIIb obtained by treatment of a MeOH soln of XVIIIa with ethereal diazomethane. The analytical sample was obtained by recrystallization from acetone and gave m.p. 191–192°. (Found: C, 54·73; H, 5·37. Calc. for $C_{18}H_{21}O_7NS$: C, 54·50; H, 5·72%); ν_{max}^{KBr} 1738, 1595, 1165, 1175 cm^{-1}; NMR ($CDCl_3$) δ 1·44 (d, J = 10 c/s, 1H), δ 1·85 (d, J = 10 c/s, 1H), δ 2·59 (S, $W_{\frac{1}{2}h}$ 4 c/s, 2H), δ 2·70 (S, $W_{\frac{1}{2}h}$ 4 c/s, 2H), δ 3·25 (S, 6H) overlapping δ 3·28 (S, $W_{\frac{1}{2}h}$ 6 c/s, 2H), δ 3·58 (S, 3H), δ 6·44 (d, J = 8 c/s, 2H), δ 7·17 (d, J = 8 c/s, 2H). After elution with 4 l. $C_6H_6CHCl_3$ mixtures a fraction was eluted with $CHCl_3$–C_6H_6 through 3:1 to MeOH–$CHCl_3$ (1:4) and crystallized from acetone to give 0·34 g of XXIa. The analytical sample was obtained by recrystallization from acetone and gave m.p. 210–212°. (Found: C, 53·33; H, 5·15. Calc. for $C_{17}H_{19}O_7NS$: C, 53·33; H, 5·36%); ν_{max}^{KBr} 3222, 1760, 1727, 1157 cm^{-1}; NMR (d_6-acetone) δ 1·67 (d, J = 12 c/s, 1H), δ 2·12 (d, J = 12 c/s, 1H), δ 3·59 (S, 3H), δ 3·91 (s, 3H), δ 4·59 (d, J = 5 c/s, 1H), δ 7·13 (d, J = 9 c/s, 2H), δ 7·83 (d, J = 9 c/s, 2H).

Preparation of endo-5-*hydroxy*-endo-6-(p-*methoxybensulfonamido*) endo–cis-2,3-*dicarboxybicyclo*{2.2.1}-*heptane* γ-*lactone* (XIX). A mixture of 0·88 g of XVIIIa and 2 ml 1·35 N NaOH was heated on the steam bath for 6 hr during which time the solid XVIIIa dissolved. After cooling, the soln was extracted with $CHCl_3$. Drying over $MgSO_4$ and evaporation of the $CHCl_3$ extract gave no residue. Upon the addition of conc HCl (5 ml) to the aqueous soln a colorless oil separated. The aqueous soln was then extracted with $CHCl_3$ and the extract was combined with the oil. Drying over $MgSO_4$ and evaporation of the $CHCl_3$ gave 0·83 g oil which crystallized to give XIX, m.p. 219–222° dec (vigorous bubbling). Recrystallization from acetone gave the analytical sample, m.p. 223–225° (dec). (Found: C, 52·55; H, 4·74. Calc. for $C_{16}H_{17}O_7NS$: C, 52·32; H, 4·63%); ; ν_{max}^{KBr} 3225, 1777, 1767, 1705 cm^{-1}; NMR (d_6- DMSO) δ 1·55 (S, 2H), δ 3·87 (S, 3H), δ 5·38 (S, 1H).

Preparation of endo-5-*hydroxy*-endo-6-(p-*methoxybenzenesulfonamido*) endo–cis-2,3-*dicarboxybicyclo*-{2.2.1}*heptane* γ-*lactone*-γ-*lactam* (XX). The lactone XIX (0·14 g, m.p. 223–235°) was heated at 225° until vigorous bubbling had ceased and then the flask was evacuated to 0·5 mm and heated an additional 5 min. The resulting glassy solid (0·13 g) was recrystallized from acetone to give the analytical sample of XX, m.p. 204–205°. (Found: C, 55·16; H, 4·41. Calc. for $C_{16}H_{15}O_6NS$: C, 55·06; H, 4·33%). ν_{max}^{KBr} 1730, 1780 cm^{-1}; NMR (d_6-DMSO) δ 1·78 (S, 2H), δ 2·93 (S, 2H), δ 3·88 (S, 3H).

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THE SYNTHESIS AND DECOMPOSITION OF A NORBORNYL ENDO Δ^2- 1,2,3-TRIAZOLINE[1]

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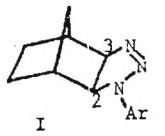
The recent observation[2,3] that norbornyl exo Δ^2-1,2,3-triazolines (I) give on pyrolysis, in addition to the expected exo-aziridines (II) and imines (III), endo aziridines (IV), prompted us to investigate the behavior of the corresponding endo triazolines (V) under similar conditions.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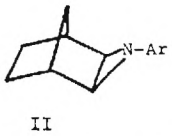
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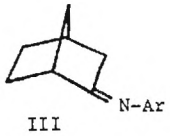
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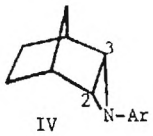
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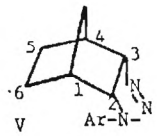
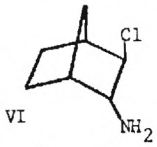

V

Unfortunately, endo triazolines cannot be obtained directly from bicyclic olefins, such as norbornylene, by the most universal synthetic method, namely, 1,3-dipolar cycloaddition of azides, since this reaction has been shown to proceed exclusively with exo orientation[2,4,5,6].

We now wish to report the synthesis of the first such endo norbornyl triazoline by a method which appears to be of general applicability[7]. The requisite endo-2-amino-exo-3-chloronorbornane (VI) was prepared from norbornylene by sequential treatment with nitrosyl chloride[8], then urea[9]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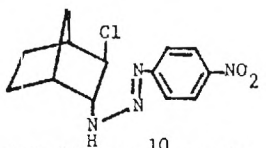

VII

to give the chloro oxime, the acetate of which was reduced with diborane[10] to give VI, which was isolated as its HCl salt [m.p. 195-200°; $\nu_{max.}^{KBr}$ 3400, 2925, 1960, 1590, 1570, 1495, 1475 cm^{-1}][11]. Chloroamine VI was also made by the same procedure via the p-nitrobenzoate ester of the intermediate oxime. The hydrochloride salt of VI was coupled with p-nitrobenzenediazonium chloride in a buffered solution to give VII in 61% yield [m.p. 112-115°, $\nu_{max.}^{KBr}$ 3380, 3315,

1600, 1500, 1320, 1250 cm^{-1}][11]. The latter intermediate was converted into the endo triazoline V (Ar = p-$NO_2C_6H_4$) in 64% yield by treatment with sodium ethoxide in ethanol in the presence of one equivalent of silver nitrate [m.p. 120-130°; $\nu_{KBr}^{max.}$ 1595, 1500, 1378, 1320 cm^{-1}; M^+-N_2, m/e 230][11]. The NMR spectrum (in $CDCl_3$) of V (Ar = p-$NO_2C_6H_4$) clearly showed that the triazoline ring was endo by the appearance of the C-2 proton as a doublet of doublets (J = 12.0, 4.25 Hz) centered at δ4.02 and the C-3 proton as a doublet of doublets (J = 12.0, 5.50 Hz) centered at δ5.09[7]. In contrast to this, the exo triazoline I (Ar = p-$NO_2C_6H_4$)[12] shows the C-2 proton as a doublet (J = 9 Hz) centered at δ 3.79 and the C-3 proton as a doublet (J = 9 Hz) centered at δ 4.77.

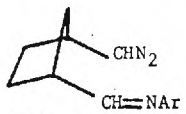
Photolysis of V, as expected[2], gave cleanly the endo aziridine IV (Ar = p-$NO_2C_6H_4$) with the C-2 and C-3 protons appearing in the NMR spectrum as a triplet (J = 2 Hz) centered at δ 2.93. Table 1 indicates the results obtained on pyrolysis[13] of the endo and exo aziridines.

Table 1.

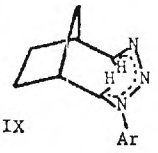
Pyrolysis of Triazolines (Ar = p-$NO_2C_6H_4$) in Decalin at 165-170°

Triazoline	Endo Aziridine IV	Exo Aziridine II	Imine III	Polymer
Exo I	8.8%	48.5%	42.3%	0
Endo V	17.5%	34.4%	48.2%	80%

We have previously suggested[2] that exo triazolines (I) yield endo aziridines (IV) via intermediate diazoimines (VIII), which could arise by a thermally allowed retro 1,3-dipolar cycloaddition reactions.



VIII



IX

Now with the observation that endo triazolines (V) yield exo aziridines (II) on pyrolysis, further support for such an intermediate is provided. However, because of the large amount of polymer produced in the pyrolysis of the endo triazoline, under the conditions recorded in Table 1, we cannot conclusively state that a common intermediate is involved in the pyrolysis of exo and endo triazolines and more than one pathway may be operative. As might be expected on thermodynamic grounds, the endo triazoline begins to evolve nitrogen (in decalin) about 30° below that observed for the exo triazoline (165°). Attempts to observe, by NMR, the interconversion of exo and endo

triazolines via intermediate VIII or via an intermediate such as IX, which could arise by a thermally allowed disrotatory electrocyclic ring opening of either triazoline, have so far not met with success. Likewise, we have so far not succeeded in trapping intermediate VIII with carboxylic acids. Further studies are underway.

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